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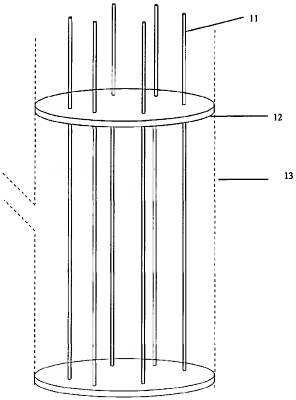
(54) Title: PREFORM, METHOD OF ITS PRODUCTION, AND USE THEREOF IN PRODUCTION OF MICROSTRUCTURED OPTICAL FIBRES



(57) Abstract: Method of making a preform for microstructured optical fibres, in an aspect the method being an improved sol-gel process, wherein elongated elements, such as rods and/or tubes, extend through a tubular vessel, and being maintained in a predetermined spatial arrangement with respect to the vessel, the elongated elements being part of a final gel body resulting from the sol-gel process; a preform or part thereof for making microstructured optical fibres, the preform comprising concentric tubes and a plurality of tubes and/or rods placed between the concentric tubes; and microstructured optical fibres produced using such preforms.

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PREFORM, METHOD OF ITS PRODUCTION, AND USE THEREOF IN PRODUCTION OF MICROSTRUCTURED OPTICAL FIBRES

DESCRIPTION

1. BACKGROUND OF THE INVENTION

The present invention relates to preforms for microstructured optical fibres, methods for producing such preforms, and use thereof in production of microstructured optical fibres.

The Technical Field

Microstructured optical fibres, also known as photonic crystal fibres, photonic band gap fibres, holey fibres and hole-assisted fibres have undergone a very rapid development in their short existence. The usual way of building preforms from stacked capillary tubes (see for example "2D Photonic band gap structures in fibre form", T. A. Birks et al., Photonic Band Gap Materials, Kluwer, 1996) is now being challenged by new schemes. The introduction of new schemes is inevitable in order to deal with issues such as impurity induced loss, PMD, reducing operator dependence, method suitability for large scale production etc. This should not be looked upon as a problem but rather as a natural consequence of the group of microstructured optical fibres being on the brink of becoming commercially interesting.

Due to the diversity of microstructured fibres and their applications, there will be a need for different fabrication schemes. Besides depending on the experience within each manufacturer also the suitability and feasibility of

each scheme strongly depend on the specific fibre design. The vast number of published fibre designs clearly displays the variety of complexity within microstructured optical fibres that will favour individual choices for best practice in production. The present inventions provides range of new methods of making preforms for microstructured optical fibres, including designs of such preforms, and designs of optical fibres that are produced using such preforms.

Prior Art Disclosures

It turns out that many standard techniques for producing conventional optical fibre preforms can be adapted to producing microstructured fibre preforms. These techniques are Chemical Vapour Deposition (CVD), currently a well-established technique to produce very low loss fibres, and the sol-gel technique, which has recently emerged as an alternative to CVD. It is a purpose of the present invention to disclose embodiments for producing microstructured fibre preforms from the sol-gel technique and from the standard implantations of the CVD technique, i.e. the OVD (Outside Vapour deposition), the VAD (Vapour Axial Deposition), the MCVD (Modified Chemical Vapour Deposition), and the PCVD (Plasma Chemical Vapour Deposition) processes (description of these processes can be found in standard text book, see for example "Glasses for photonics", M. Yamane, Y. Asahara, Cambridge University Press, ISBN 0 521 58053 6; "Method of making microstructured optical fiber by sol-gel process", European Patent Application EP 1 172 339 A1, D Hazan et al., Lucent Technologies Inc.; "Manufacture of vitreous silica product via a sol-gel process using a polymer additive", US patent 5,240,488, Aug. 31, 1993; Optical Materials 4 (1994) 181-185 E.M. Dianov et al.; "An overview of the

Modified Chemical Vapor Deposition (MCVD) Process and Performance", J. Quantum Electron., Vol. QE-18, No. 4, April 1982, S. R. Nagel, J. B. MacChesney, K. L. Walker).

With the emergence of new fabrication processes for optical fibres, it is also widely recognized that new fibre geometries or fibre designs are possible. Circular structures are particularly interesting and have several advantages over the hexagonal structures of the usual stacking technique. For example they are expected to have reduced polarization mode dispersion (PMD) as well as to better match the mode structure of conventional fibre (an important issue for connectorisation).

In US patent application 2001/0028775 A1 optical fibres based on concentric microstructured layers have been disclosed together with calculations of dispersion properties. However no fibre was realized and methods of making the fibres were not disclosed. In European patent application EP 1 199 581 A1 multimode concentric microstructured fibres with graded index profile were disclosed together with the sol/gel technique used to fabricate them. No mention was made of the losses in the fabricated fibres.

It turns out that an advantageous scheme for fabricating preforms or parts thereof for microstructured fibres using concentric layers of glass parts can be obtained.

These here-disclosed schemes provide a number of advantages, including facilitating production of preforms for microstructured fibres and of microstructured fibres, thereby resulting in a gain in productivity and product quality. Another advantage of the here-disclosed schemes and methods is that they further enable the realization

of microstructured optical fibres with a number of new designs.

The stability observed in this circular type of microstructured fibres is further advantageous in order to provide low PMD values due to the strong uniformity.

2. DISCLOSURE OF THE INVENTION

Object of the Invention

It is an object of the present invention to seek to provide improved microstructured optical fibres.

It is a further object of the present invention to seek to provide improve preforms for production of such microstructured optical fibres.

It is a further object of the present invention to seek to provide improved methods for making such preforms.

Further objects appear from the description elsewhere.

Solution According to the Invention

According to the present invention there is provided several methods of making a preform for a microstructured optical fibre as recited in the appended claims.

According to a first aspect of the invention there is provided a method of making a preform for a microstructured optical fibre, said method comprising the steps:

a) providing a tubular vessel having a length;
b) providing a plurality of elongate elements extending at least a portion of said length and being maintained in a predetermined spatial arrangement with respect to the vessel;
c) filling at least a portion of said vessel with a silica-containing sol;
d) permitting or causing said sol to gel to thereby form a wet gel body; and
e) drying said wet gel body, such that a dried or at least partly dried gel body comprising said plurality of elongate elements results.

In a preferred embodiment, step c) is performed before step b).

In a preferred embodiment, step e) includes or further includes sintering of the gel body.

In a preferred embodiment, the sintering process is performed after the drying process, such that a dried or at least partly dried and sintered gel body comprising said plurality of elongate elements results.

In a preferred embodiment, step e) further includes purifying of the gel body, such that a dried or at least partly dried, purified and sintered gel body comprising said plurality of elongate elements results.

In a preferred embodiment, the elongate elements are maintained in the predetermined arrangement by holding fixtures.

In a preferred embodiment, the vessel is removed after the gelation process of step d) and before the drying process of step e).

In a preferred embodiment, the holding fixtures are removed after the gelation process of step d) and before the drying process of step e).

In a preferred embodiment, the sintering process is performed at a temperature in the range of 1100-1600 °C or in the range of 1300-1500 °C.

In a preferred embodiment, the sintering process is performed at a temperature in the range of 1200-1750 °C.

In a preferred embodiment, the elongate elements comprise one or more capillary tubes and/or one or more rods.

In a preferred embodiment, at least part of the one or more capillary tubes is sealed before the filling of at least a portion of said vessel with the sol.

In a preferred embodiment, at least a part of the sealed capillary tubes are unsealed after the drying or sintering process.

In a preferred embodiment, the one or more rods comprise one or more doped rods.

In a preferred embodiment, the dried or sintered body is sleeved in an overclad tube.

In a preferred embodiment, a compound glass is added to one or more of the capillary tubes after the drying or sintering process.

In a preferred embodiment, the compound glass contains less than 70% of silica.

In a preferred embodiment, a gas is added to one or more of the capillary tubes.

In a preferred embodiment, said gas filled capillary tubes are sealed after the adding of gas.

In a preferred embodiment, the gas is added to the capillary tubes after the drying or sintering process.

In a preferred embodiment, the added gas is containing chlorine or fluorine or an inert gas.

In a preferred embodiment, the gel body has a diameter or largest cross-sectional dimension in the range of 10-150 mm or in the range of 20-100 mm.

In a preferred embodiment, the gel body has a length larger than 100mm or in the range of 150-1200 mm.

In a preferred embodiment, said method comprising using a preform as previously described in one or more of the preferred embodiments.

In a preferred embodiment, a gas is flowing through a number of open capillary tubes during at least part of the drawing process.

In a preferred embodiment, the flowing gas is containing chlorine or fluorine or an inert gas.

According to a second aspect of the invention there is provided a method of making a preform for a microstructured optical fibre, said method comprising

(a) casting at least one sol-gel preform element having a length and a number of grooves extending at least a portion of said length, said grooves being arranged on an outer surface and/or an inner surface of the sol-gel element, and

(b) for grooves being arranged on the outer surface of the sol-gel element, providing one or more outer cover preform elements for covering the outer grooves at least partly along said length, and/or

(c) for grooves being arranged on the inner surface of the sol-gel element, providing one or more inner cover preform elements for covering the inner grooves at least partly along said length;

said covering of the outer and/or inner grooves thereby providing a number of elongated holes extending in the direction of the length of the preform elements.

In a preferred embodiment, said at least one sol-gel element comprises an inner sol-gel preform element having a number of grooves being arranged on the outer surface of the inner sol-gel element.

In a preferred embodiment, said at least one sol-gel preform element comprises one or more tubular formed sol-gel elements having a number of grooves being arranged on the outer surface of the element and/or the inner surface of the element.

In a preferred embodiment, said at least one sol-gel preform element comprises a first number of curve-shaped elements with a number of outer and/or inner grooves, said first number of curve-shaped elements being arranged so as to form a first compound tube with outer and/or inner grooves.

In a preferred embodiment, at least one of said one or more tubular formed sol-gel elements is used as an outer or inner cover preform element.

In a preferred embodiment, said first compound tube formed element is used as an outer or inner cover preform element.

In a preferred embodiment, the casting of a sol-gel preform element comprises:

a) providing a vessel having a length and formed as a mould for said sol-gel preform element, said vessel being provided with a number of projections extending inside in the vessel and along at least a portion of the length of the vessel, said projections thereby serving as a mould for said number of grooves;
b) filling at least a portion of said vessel with a silica-containing sol;
c) permitting or causing said sol to gel to thereby form a wet gel body; and
d) drying said wet gel body, such that a dried or at least partly dried gel body comprising said number of grooves results.

In a preferred embodiment, step d) includes or further includes sintering of the gel body.

In a preferred embodiment, the sintering process is performed after the drying process, such that a dried or at least partly dried and sintered gel body comprising said number of grooves results.

In a preferred embodiment, step d) further includes purifying of the gel body, such that a dried or at least partly dried, purified and sintered gel body comprising said number of grooves results.

In a preferred embodiment, the sol-gel preform element has a diameter or largest cross-sectional dimension in the range of 10-150 mm or in the range of 20-100mm.

In a preferred embodiment, the sol-gel preform element has a length larger than 100 mm or in the range of 150-1200 mm.

According to a third aspect of the invention there is provided a method of making a preform for a microstructured optical fibre, said method comprising:

a) providing a deposition tube having a length;
b) providing a plurality of elongate elements extending at least a portion of said length and being maintained in a predetermined spatial arrangement with respect to the deposition tube; and
c) performing a Chemical Vapor Deposition, CVD, process to thereby deposit a doped glass material in the tube until the elongated elements are at least partly buried by the deposited material, such that a preform body comprising said plurality of elongate elements results.

In a preferred embodiment, said deposition process comprises a Modified Chemical Vapor Deposition, MCVD, process or a plasma Chemical Vapor Deposition, plasma CVD, process.

In a preferred embodiment, the elongate elements are maintained in the predetermined arrangement by holding fixtures.

In a preferred embodiment, the holding fixtures comprises two discs, each disc having a first number of holes for placement of the elongate elements and a second number of holes for allowing a flow of process gas.

In a preferred embodiment, the holding fixtures are made of quartz or silica.

In a preferred embodiment, the holding fixtures are fused to the deposition tube by heating.

In a preferred embodiment, the elongate elements comprise one or more capillary tubes and/or one or more rods.

In a preferred embodiment, the elongate elements comprise one or more doped or un-doped silica rods.

In a preferred embodiment, the elongate elements comprise one or more doped or un-doped capillary silica tubes.

In a preferred embodiment, the preform body has a diameter or largest cross-sectional dimension in the range of 10-150 mm or in the range of 20-100 mm.

In a preferred embodiment, the preform body has a length larger than 100 mm or in the range of 150-1200 mm.

According to a fourth aspect of the invention there is provided a method of making a preform for a microstructured optical fibre, said method comprising:

a) providing a deposition rod having a length;
b) providing a plurality of elongate elements extending at least a portion of said length and being maintained in a predetermined spatial arrangement with respect to the deposition rod; and
c) performing a Chemical Vapor Deposition, CVD, process to thereby deposit a doped glass material around the deposition rod until the elongated elements are at least partly buried by the deposited material, such that a preform body comprising said plurality of elongate elements results.

In a preferred embodiment, the deposition process comprises a VAD or an OVD deposition process.

In a preferred embodiment, said method further comprising one or more sintering processes during the deposition of the doped glass material.

In a preferred embodiment, said method further comprising the removal of the deposition rod after the deposition of the doped glass material.

In a preferred embodiment, the elongate elements are maintained in the predetermined arrangement by holding fixtures.

In a preferred embodiment, the holding fixtures comprises two discs, each disc having a first number of holes for

placement of the elongate elements and a rod hole for placement of the deposition rod.

In a preferred embodiment, the holding fixtures are made of quartz or silica.

In a preferred embodiment, the holding fixtures are fused to the deposition tube by heating.

In a preferred embodiment, the elongate elements comprise one or more capillary tubes and/or one or more rods.

In a preferred embodiment, the elongate elements comprise one or more doped or un-doped silica rods.

In a preferred embodiment, the elongate elements comprise one or more doped or un-doped capillary silica tubes.

In a preferred embodiment, the preform body has a diameter or largest cross-sectional dimension in the range of 10-150 mm or in the range of 20-100 mm.

In a preferred embodiment, the preform body has a length larger than 100 mm or in the range of 150-1200 mm.

According to a fifth aspect of the invention there is provided a method of making a preform for a microstructured fibre, said method comprising:

a) providing a porous or non-solid silica containing body having a length;
b) forming a number of elongate holes or voids extending at least a portion of said length, and after said formation of elongate holes or voids; and

c) permitting or causing said silica containing body to solidify.

In a preferred embodiment, step c) includes sintering of the body.

In a preferred embodiment, said porous or non-solid silica containing body is provided by use of a tubular vessel having a length, filling at least a portion of said vessel with a silica-containing sol, and permitting or causing said sol to gel to thereby form a gel body.

In a preferred embodiment, said porous or non-solid silica containing body is provided by use of a deposition rod having a length, performing a chemical vapour deposition process to thereby deposit doped glass on the deposition rod until at least a part of the deposition rod is covered with doped glass.

In a preferred embodiment, said deposition process comprises a so-called VAD or a so-called OVD deposition process.

In a preferred embodiment, the body is removed from the vessel before the formation of the elongate holes or voids.

In a preferred embodiment, the body is at least partly dried without being sintered before the formation of the elongate holes or voids.

In a preferred embodiment, the body is purified the sintering process.

In a preferred embodiment, the elongate holes or voids are formed by a drilling process.

In a preferred embodiment, the drilling process comprises a rotary or an ultra sonic drilling process.

In a preferred embodiment, the formed holes or voids are washed and etched.

In a preferred embodiment, the elongate holes or voids are formed by use of laser.

In a preferred embodiment, a CO_2 laser is used for said formation of holes or voids.

In a preferred embodiment, one or more rods are inserted in the formed holes or voids after the solidification.

In a preferred embodiment, one or more tubes are inserted in the formed holes or voids after the solidification.

In a preferred embodiment, one or more of said rods and/or tubes are made of a doped material.

In a preferred embodiment, the solidified body has a diameter or largest cross-sectional dimension in the range of 10-150 mm or in the range of 20-100 mm.

In a preferred embodiment, the solidified body has a length larger than 100 mm or in the range of 150-1200 mm.

In a preferred embodiment, the elongate holes or voids formed in step d) have a diameter or largest cross sectional dimension larger than 0.8 mm.

In a preferred embodiment, the elongate holes or voids formed in step d) have a length larger than 50 mm.

According to a sixth aspect of the invention there is provided a method of making a preform for a microstructured optical fibre, said method comprising:

a) providing a plurality of electrically resistive elements extending in a longitudinal direction and being maintained in a predetermined spatial arrangement with respect to said longitudinal direction;
b) forming a porous or non-solid silica containing body surrounding said electrically resistive elements; and
c) performing an at least local solidification of the porous body around the electrically resistive elements by providing an electrical current through at least part of said elements to thereby create a gap around each of said elements being provided with an electrical current.

In a preferred embodiment, the electrically resistive elements are arranged substantially parallel along said longitudinally direction.

In a preferred embodiment, said method further comprising removal of the electrically resistive elements after said local solidification, whereby the created gaps leaves a number of elongate holes or voids extending in said longitudinally direction.

In a preferred embodiment, said method further comprising permitting or causing said silica containing body to solidify after the removal of the electrically resistive elements.

In a preferred embodiment, said method further including sintering of the body.

In a preferred embodiment, said porous or non-solid silica containing body is provided by use of a tubular vessel having a length and surrounding the electrically resistive elements, filling at least a portion of said vessel with a silica-containing sol, and permitting or causing said sol to gel to thereby form a gel body at least partly surrounding said electrically resistive elements.

In a preferred embodiment, said porous or non-solid silica containing body is provided by use of a deposition rod having a length and being surrounded by the electrically resistive elements, performing a chemical vapour deposition process to thereby deposit doped glass around the deposition rod until at least a part of the deposition rod is covered with doped glass and until the electrically resistive elements are at least partly buried by the deposited material.

In a preferred embodiment, said deposition process comprises a so-called VAD or a so-called OVD deposition process.

In a preferred embodiment, the body is purified before the sintering process.

In a preferred embodiment, one or more rods are inserted in the formed holes or voids.

In a preferred embodiment, one or more tubes are inserted in the formed holes or voids.

In a preferred embodiment, one or more of said rods and/or tubes are made of a doped material.

In a preferred embodiment, the silica containing body has a diameter or largest cross-sectional dimension in the range of 10-150 mm or in the range of 20-100 mm.

In a preferred embodiment, the silica containing body has a length larger than 100 mm or in the range of 150-1200 mm.

In a preferred embodiment, the formed gaps have a diameter or largest cross sectional dimension larger than 0.2 mm or larger than 0.8 mm.

In a preferred embodiment, the formed gaps are extending in all the length of the silica containing body.

According to a seventh aspect of the invention there is provided a method of making a preform for a microstructured optical fibre, said method comprising:

a) providing a silica tube or rod having a length,
b) forming a number of elongate holes or voids extending at least a portion of said length, and
c) performing a plasma deposition of a doped glass material in one or more of the formed holes or voids.

In a preferred embodiment, the deposition process is plasma Chemical Vapor Deposition, PCVD, process.

In a preferred embodiment, a plasma coil is arranged around the silica tube or rod for use during the plasma deposition process.

In a preferred embodiment, the elongate holes or voids are formed by a drilling process.

In a preferred embodiment, the drilling process comprises a rotary or an ultra sonic drilling process.

In a preferred embodiment, the formed holes or voids are washed and/or etched.

In a preferred embodiment, the elongate holes or voids are formed by use of laser.

In a preferred embodiment, the doped glass material comprises a dopant selected from the group of dopants comprising: Ge, P, Sn, N, B and F.

In a preferred embodiment, the silica tube or rod has a diameter or largest cross-sectional dimension in the range of 10-150 mm or in the range of 20-100 mm.

In a preferred embodiment, the silica tube or rod has a length larger than 100 mm or in the range of 150-1200 mm.

In a preferred embodiment, the elongate holes or voids formed in step b) have a diameter or largest cross sectional dimension larger than 0.2 mm or larger than 0.8 mm.

In a preferred embodiment, the elongate holes or voids formed in step b) have a length larger than 50 mm or larger than 100 mm.

In a preferred embodiment, the elongate holes or voids formed in step b) are extending in all the length of the silica tube or rod.

According to an eighth aspect of the invention there is provided a method of making a preform for a micro-structured optical fibre, said method comprising:

a) providing a glass containing body having a length,
b) forming a number of elongate holes or voids extending at least a portion of said length, and
c) inserting one or more rods and/or capillary tubes in the formed holes or voids.

The elongate holes may be formed in several ways, but according to one embodiment it is preferred that the elongate holes or voids are formed by a drilling process. Here, the drilling process may comprise a rotary or an ultra sonic drilling process. It is preferred that the formed holes or voids are washed and etched.

As an alternative, the elongate holes or voids may be formed by use of laser. Here, a CO2 laser may be used for the formation of holes or voids.

It is preferred that one or more of the rods or capillary tubes are made of a doped material. Here, the doped material may be a doped silica material. Such doped silica material may comprise a dopant selected from the group of dopants comprising: Ge, P, Sn, N, B and F and rare-earths.

Several dimensions may be used when forming the glass containing or glass body. Thus, the glass containing body may have a diameter or largest cross-sectional dimension larger than 5 mm, such as in the range of 5-150 mm or in

the range of 20-100 mm. It is also preferred that the glass containing body has a length larger than 20 mm, such as in the range of 20-500 mm or in the range of 150-1200 mm. Preferably, the glass containing body is cylindrically shaped. For the elongate holes or voids formed in step b) it is preferred that they have a diameter or largest cross sectional dimension larger than 0.5 mm or larger than 0.8 mm, or in the range of 0.5-10 mm. For the length of the elongate holes or voids formed in step b), it is preferred that they have a length larger than 20 mm, larger than 50 mm, or larger than 100mm, or in the range of 20-500 mm. It is also within a preferred embodiment that the elongate holes or voids formed in step b) are extending in all the length of the glass containing body.

The glass body or glass containing body may be made of different glass materials, but according to a preferred embodiment the glass containing body is a synthetic silica body. The glass containing body may also or alternatively be a doped silica body comprising a dopant selected from the group of dopants comprising: Ge, P, Sn, N, B and F and rare-earths.

According to a ninth aspect of the invention there is provided a preform for a microstructured optical fibre, where the preform comprises a number of cylindrically shaped bodies having substantially equal radial dimensions, each said body having a number of spaced apart through-holes extending in a longitudinal direction along the axis of the body, and the radial position of at least part of said through-holes being substantial equal for each of the bodies. The bodies may be stacked so as to align at least part of the through-holes of the bodies in

the axial direction, and an outer tube may be contactingly surrounding at least part of the stacked bodies.

For the ninth aspect of the invention it is preferred that the bodies are stacked so that one or more elongate holes extending through several of the bodies are obtained via the aligned through-holes. Thus, at least two or three of said elongate holes may be obtained, but it is also within the present invention to have a larger number of such elongate holes, and the number of elongate holes extending through several of the bodies may be in the range of 3-300. Preferably, said one or more elongate holes extend through at least two or three bodies.

According to a preferred embodiment, the number of stacked bodies is at least two or at least three, but the present invention also covers a larger number of stacked bodies such as four or larger. In order to obtain a good stacking and/or alignment, it is preferred that each or at least part of the cylindrically shaped bodies has a substantially planar front surface and/or back surface. Here, each or at least part of the substantially planar front surface(s) and/or back surface(s) may have been grinded and/or polished.

It should be understood that one of the purposes of stacking the bodies is to obtain a relatively long preform. Thus, it is preferred that the length of each of the cylindrically shaped bodies is larger than the diameter of the body. However, the ninth aspect of the present invention also covers an alternative embodiment in which the diameter of one or more of the bodies is larger than the length of the corresponding body.

For the preform according to the ninth aspect of the invention it is within a preferred embodiment that the preform further comprises one or more rods and/or capillary tubes being inserted in the aligned through-holes of at least two successively arranged bodies. Here, one or more of said rods or capillary tubes may be made of a doped material, such as a doped glass or silica material. Such doped glass or silica material may comprise a dopant selected from the group of dopants comprising: Ge, P, Sn, N, B and F and rare-earths.

According to an embodiment of the ninth aspect of the invention, the preform may further comprise a cylindrically shaped dummy body arranged at the top of the stacked bodies having through-holes. Here, the top dummy body should preferably have substantially equal radial dimensions as said stacked bodies with through-holes, and the top dummy body may be contactingly surrounded by the outer tube. Similarly, the preform may also or alternatively comprise a cylindrically shaped dummy body arranged at the bottom of the stacked bodies with through-holes. Also the bottom dummy body should have substantially equal radial dimensions as said stacked bodies with through-holes, and the bottom dummy body may be contactingly surrounded by the outer tube. The top and/or bottom dummy body need not to have any aligned through-holes, and thus may have no through-holes or the number of through-holes in a dummy body may be smaller than the number of through-holes in any of the stacked bodies with through-holes.

When preparing or fabricating the preform according to the ninth aspect of the invention, it is preferred that the stacked bodies are aligned by use of one or more

alignment rods and/or tubes inserted in one or more of the through-holes of the bodies to be aligned.

The stacked bodies may be made of different materials, but it is preferred that they are made of a glass material. Similarly, it is preferred that the dummy body or bodies are made of a glass material. Such glass material may be a synthetic silica material, or the glass material may be a doped silica material. Here, the doped silica material may comprise a dopant selected from the group of dopants comprising: Ge, P, Sn, N, B and F and rare-earths.

Also for the ninth aspect of the invention, several dimensions may be used when forming the cylindrically shaped bodies to be stacked. Thus, the cylindrically shaped bodies may have a diameter or largest cross-sectional dimension larger than 5 mm, such as in the range of 5-150 mm or in the range of 20-100 mm. It is also preferred that the cylindrically shaped bodies have a length larger than or equal to 20 mm, larger than or equal to 50 mm, or larger than or equal to 100 mm. For the through-holes of the bodies it is preferred that they have a diameter or largest cross sectional dimension larger than 0.5 mm or larger than 0.8 mm, or in the range of 0.5-10 mm.

It should be understood that in order to provide the number of bodies with through-holes used in the preform according to the ninth aspect of the invention, a drilling process similar to the drilling process used when making a preform according to an embodiment of the eighth aspect of the invention may be used. Alternatively, the through-holes may be formed by use of a laser such as a CO_2 laser.

In still another aspect of the invention there is provided a preform or part thereof for a microstructured optical fibre, said preform or part comprising:

a) an inner tube or inner rod having a length;
b) a first plurality of cladding tubes and/or rods arranged around said inner tube or rod and extending at least a portion of said length; and
c) a first outer tube surrounding said first plurality of cladding tubes and/or rods.

In still another aspect of the invention there is provided a preform or part thereof for a microstructured optical fibre, said preform or part comprising:

a) an inner tube or inner rod having a length;
b) a first grooved tube having elongated slits and/or grooves extending at least a portion of said length, said first grooved tube surrounding said inner tube or rod; and
c) a first outer tube surrounding said first grooved tube.

In a preferred embodiment, a number of pluralities of cladding tubes and/or rods extending at least a portion of said length are arranged in corresponding outer tubes concentrically about the inner tube or inner rod.

In a preferred embodiment, one or more of the corresponding outer tubes comprises a number of slits and/or grooves extending at least a portion of said length.

In a preferred embodiment, a number of grooved tubes having elongated slits and/or grooves extending at least

a portion of said length are arranged concentrically about the inner tube or inner rod.

In a preferred embodiment, each of said number of grooved tubes is surrounded by a corresponding solid outer tube.

In a preferred embodiment, the number of pluralities of cladding tubes and/or rods is at least two, with the second plurality being surrounded by a second outer tube.

In a preferred embodiment, said second plurality of cladding tubes and/or rods is arranged around the first outer tube.

In a preferred embodiment, the number of pluralities of cladding tubes and/or rods is at least three, with the third plurality being surrounded by a third outer tube.

In a preferred embodiment, said third plurality of cladding tubes and/or rods is arranged around the second outer tube.

In a preferred embodiment, the number of pluralities of cladding tubes and/or rods is at least four, with the fourth plurality being surrounded by a fourth outer tube.

In a preferred embodiment, said fourth plurality of cladding tubes and/or rods is arranged around the third outer tube.

In a preferred embodiment, said number of pluralities of cladding tubes and/or rods is at least five, six or seven.

In a preferred embodiment, one or more plurality of cladding rods comprise one or more doped or un-doped silica rods.

In a preferred embodiment, one or more plurality of cladding tubes comprise one or more doped or un-doped silica tubes.

In a preferred embodiment, the first plurality of cladding tubes and/or rods is arranged in a single layer only around said inner tube or rod.

In a preferred embodiment, the first plurality of cladding tubes and/or rods is arranged in two layers around said inner tube or rod.

In a preferred embodiment, the first plurality of cladding tubes and/or rods is arranged in three, four, five or six layers around said inner tube or rod.

In a preferred embodiment, the second plurality of cladding tubes and/or rods is arranged in a single layer only being surrounded by said second outer tube.

In a preferred embodiment, the second plurality of cladding tubes and/or rods is arranged in two layers only being surrounded by said second outer tube.

In a preferred embodiment, the second plurality of cladding tubes and/or rods is arranged in three, four, five or six layers only being surrounded by said second outer tube.

In a preferred embodiment, one or more plurality of cladding tubes and/or rods is arranged in a single layer only being surrounded by the corresponding outer tube.

In a preferred embodiment, one or more plurality of cladding tubes and/or rods is arranged in two layers only being surrounded by the corresponding outer tube.

In still another aspect, the present invention provides a microstructured fibre made from a preform or parts thereof according to the invention.

3. BRIEF DESCRIPTION OF THE DRAWINGS

In the following, by way of examples only, the invention is further disclosed with detailed description of preferred embodiments. Reference is made to the drawings in which

Fig. 1a shows a sol-gel vessel 13 similar to that described in prior art. However, the elements here 11 become elements in the final fibre and hence will not be removed from the sol-gel.

Fig. 1b shows an example showing the principle in a preform. A doped rod 14 and a sealed tube 15 is embedded in the sintered sol-gel body 16.

Fig. 1c shows the main steps in a sol-gel process. The solution containing Si is mixed with water in a container together with additives. The solution is loaded into the vessel. After formation of the wet gel body, it is gently removed from the vessel to dry. The porous gel body is treated with gasses in order to remove remaining

substances such as water and additives. Finally, the preform is sintered to dense glass.

Fig. 2a shows the principle of a multiple piece sol-gel preform 25. One central element 21 and the first outer element are shown 22. Several of such outer elements are of course possible. In this case four of the grooves 23 form holes in the final preform and the extra feature (shown as a groove in the outer element 27 and a moulding 28 on the inner element serves to ensure proper angular alignment).

Fig. 2b shows an alternative version where the outer element is split. Features for ensuring proper alignment can also be made here (not shown).

Fig. 3 shows an assembly of rod and/or capillary tube elements 31 are placed in a couple of discs 32 (preferably of quartz) for ensuring their positions. This again is placed in a deposition tube 33. Process gasses are let through the tube as a standard MCVD or PCVD process, and the elements are embedded in the final preform.

Fig. 4 an assembly of rod and/or capillary tube elements 41 are placed in a couple of discs 42 (preferably of quartz) for ensuring their positions. The discs are placed on a deposition rod or tube 43 and the deposition process can be OVD. The element array is embedded in the final preform.

Fig. 5 shows a CO_2 laser "drilling" of a sol-gel body 52 before the sintering step. The holes can be placed arbitrarily. The method has the advantage of being highly clean.

Fig. 6 shows a vessel for casting a sol-gel body 63. In the vessel there are a top plate 62 and a bottom plate 64 that hold high temperature electrical conducting wires 61. When the sol has gelled, and has been removed from the vessel and dried, strong currents are let through the wires which cause the gel to solidify locally.

Fig. 7 a quartz rod/cylinder 71 (could alternatively be a tube) is depicted with holes that have been drilled mechanically. By letting process gas 73 in through the holes and placing a plasma coil 74 around the cylinder plasma, CVD can be carried out. The holes can have individual dopants in the deposited glass.

Fig. 8 is a schematic illustration of a prior art preform made by hexagonal stacking of capillary tubes and doped rods.

Fig. 9 is a picture of a cane obtained from pulling the preform illustrated in Fig. 8.

Fig. 10 is a schematic illustration of a preform manufactured according to an embodiment of the present invention, in which holes have been drilled in a quartz cylinder with doped rods arranged in part of the holes.

Fig. 11 is a schematic illustration of a preform according to another preferred embodiment of the present invention, in which glass discs or rods with holes are stacked in a sleeving tube so as to align the holes of the discs or rods.

Fig. 12a illustrates the stacking technique employed for the first realization of photonic crystal fibres.

Fig. 12b illustrates the stacking technique for commercially available photonic crystal fibres.

Fig. 12c illustrates the difficulty of stacking in a tube 122 when a larger element 121 is inserted between the elements 120.

Fig. 13a is a schematic illustration of one of the proposed schemes for concentric stacking. Fig. 13b is another schematic illustration of one of the proposed schemes for concentric stacking.

Fig. 14a is a circular preform made of concentric embedded tubes with grooves 302 in which elements 300 are inserted.

Fig. 14b is a circular preform made of concentric embedded tubes with slits 312 in which elements 310 are inserted.

Fig. 15a is a schematic illustration of a preform based on the concentric stacking scheme illustrated in Fig. 13 or Fig. 13b.

Figs. 15b and 15c are schematic illustration of fibres obtained from pulling the preform illustrated in Fig. 15a.

Fig. 16a and 16b show circular structures consisting of an inner tube 501 surrounded coaxially by an outer tube 502, the gap between the tubes 503 being filled with unsealed 504 and sealed elements 505, respectively.

Fig. 17a shows a preform 600 consisting of a concentric stack of circular holey elements 601,602, and 603.

Fig. 17b shows different rods, tubes, or slitted-tubes (doped or undoped) or combinations of these for filling of a gap between concentric tubes. As it can be seen a great number of combinations are possible.

Fig. 18a and 18b are pictures of a structure at cane (5 mm diameter) and fibres (200 μm diameter) dimensions, respectively, obtained by pulling a preform assembled as illustrated in Fig. 16b with a solid rod instead of the tube 501.

Fig. 19a and 19b show examples of fibres which can be obtained from concentric designs.

Fig. 20a and 20b shows two preform assemblies for canes.

Fig. 20c shows a concentric stack of the two canes obtained from pulling the elements of Fig. 20a and 20b.

Fig. 20d is an example of fibres obtained from pulling the stack shown in Fig. 20c.

Fig. 21 is a schematic illustration of one of the proposed schemes for concentric stacking based on adequate choice of the radii of the elements for each concentric layer.

Fig. 22a is a schematic illustration of a preform made of 4 concentric layers of capillaries 1100 with a central hole 1102 (N=16 capillaries per layer) around a central element 1101.

Fig. 22b is a schematic illustration of a fibres obtained from pulling the preform illustrated in Fig. 22a.

Fig. 22c is similar to Fig. 22a but the capillaries 1100 are replaced by the rods 1120.

Fig. 22d is a schematic illustration of a fibre obtained from pulling the preform illustrated in Fig. 22c.

Fig. 23a is a schematic illustration of a concentric structure with 4 layers of N=16 elements. Each individual element may be a rod or a tube.

Figs. 23b, 23c, 23d, and 23e are examples of fibre structures that can be obtained from the basic structure shown in Fig. 23a using suitable choice of tube or rod for the various elements.

Fig. 24a shows a fibre based on the concentric stacking principle illustrated in Fig. 21. The core radius and normalized hole size are indicated.

Fig. 24b shows the fibre structure from Fig. 24a with an up-doped rod added to the core region.

Fig. 24c is a schematic illustration of a fibre with multiple doped regions. An up-doped rod has been added to the core, as in Fig. 24b, and an up-doped ring has been added, corresponding to stacking the second ring of holes from up-doped capillary tubes.

Figs. 25a,25b,and 25c show cut-off properties for fibre structure shown in Fig. 24a for hole sizes 20%, 30%, 60%, respectively.

Fig. 26a shows cut-off and dispersion properties for fibre structure shown in Fig. 24b (doped core) for a hole size of 20%.

Fig. 26b shows cut-off properties for fibre structure shown in Fig. 24b (doped core) for a hole size of 30%.

4. DETAILED DESCRIPTION

The first aspect of the present invention relates to a microstructured optical fibre preform produced by a sol-gel method.

Recently, a method of fabrication of microstructured optical fibres by casting a holey structure in a sol-gel has been suggested (see EP1172339 that is incorporated herein by reference). It is based on the sol-gel technique already used for fabricating sleeving tubes used in standard preform fabrication, wherein elements (such as rods, tubes, wires, or fibres) are removed from the gel thereby forming holes therein. Lubricants can be added to the elements before the sol is added to a vessel.

It is a disadvantage of the method disclosed in EP1172339 that the elements are removed as part of the preform fabrication process.

The present inventors have realized that it is an advantage to use pre-manufactured elements that are going to constitute a part of the final preform and fibre itself. According to the present invention, elements, such as undoped and/or doped glass rods (e.g. silica based glass) and/or capillary tubes (for example sealed and/or unsealed at one or more ends) may be held in a fixture according to the design of interest (see schematic illustration in fig. 1). Fig. 1a shows sol-gel vessel 13 similar to that described in prior art. How-

ever, the elements 11 here become elements in the final fibre and hence will not be removed from the gel. The sol may be added as described in prior art (EP1172339). The fixture 12 may be removed from the elements when the gel body is removed from the vessel 13. The difference compared to prior art is that the elements remain in the gel during drying, purification and sintering, see Fig. 1b, where a doped rod 14 and a sealed tube 15 are embedded in the sintered sol-gel body 16.

The process steps are illustrated in Fig. 1c. In the first step a silicon alkoxide is mixed with water. Silica particles, generally produced by flame hydrolysis and other additives may also be mixed in the solution, see US 5,240,488 for more details. The solution is then poured in a mould containing the added elements. The solution undergoes gelation, resulting in a porous body with embedded elements. Drying and purification of the gel body is carried out in furnaces, followed by the sintering to the preform, a solid body with embedded elements.

The hereby formed preform may be drawn to fibre - as possible by a person skilled in the art of drawing microstructured fibres - or the preform may be stretched prior to fibre drawing. The preform may also be sleeved prior to any of the two afore-mentioned steps or during these. Capillary tubes might be unsealed prior to draw and etched or flushed with dry gasses that will avoid hydrogen to enter. The unsealed capillary tubes might be pressure controlled during draw if necessary.

Some of the advantages of the present invention as compared to the prior art preform fabrication using sol-gel include

- The gel will not suffer from the load that is inevitably applied to it in attempts of removing elements. In prior art this load is claimed to have a tendency to form cracks,
- No contaminating lubricants are added as in the prior art for facilitating removal of elements.

The possibility of adding different dopants exists in the here-disclosed scheme. Softer glasses may for example be added in capillary tubes after the sintering step if desired.

In a second aspect, the present invention relates to casting a microstructured optical fibre preform in a number of elements.

A microstructured optical fibre preform can be cast in a number of elements (see figs. 2a and 2b).

Fig. 2a depicts the principle of a multiple piece sol-gel preform. One central element 21 and the first outer element 22 are shown. Several of such outer elements are of course possible. In this case four of the grooves 23 form holes 24 in the final preform 25 and the extra feature 26 (shown as a groove 27 in the outer element 22 and a moulding 28 on the inner element 21 serves to ensure proper angular alignment).

Fig. 2b shows an alternative version, where the outer element is split 2100, 2110. Features for ensuring proper alignment can also be made here (not shown).

The casting of a preform according to the invention will result in a larger surface to volume ratio easing the drying step and reducing the risk of crack formation. In-

stead of casting holes, only grooves or grooves in combination with holes are cast. This ensures access to the inner of what will be holes in the assembled preform allowing polishing, deposition of film on the groove surface etc. When all elements for a preform are cast the preform may be assembled in a sleeving tube and fused by drawing it to a cane on a drawing tower (or directly to fibre). Subsequently it may be drawn to fibre while controlling the pressure in the holes. Alternatively, prior to drawing, the cane may act as an inner element for a larger preform though still allowing pressure control of the holes. The preform may for example consist of an inner element cast separately surrounded by a number of ring-like elements. A guiding feature may be made in order to ensure proper alignment of the elements in the assembly. The elements can also be made with outer elements being split as schematically shown in Fig. 2b.

In a third aspect, the present invention relates to microstructured optical fibre preform fabrication by in-build rods and tubes in chemical vapour deposition (CVD) processes.

The present inventors have realized an improved scheme that involves doped or undoped silica rods or capillary tubes. These elements may be held in a fixture in order to preserve their positions during processing. The first variant is combined with MCVD or plasma CVD (see schematic illustration in Fig. 3). Fig. 3 shows an assembly of rod and/or capillary tube elements 31 placed in a couple of discs (preferably of quartz) 32 for ensuring their positions. This again is placed in an MCVD tube 33. MCVD process gasses 34, such as $SiCl_4$, $GeCl_4$, $POCl_3$, BBr_3, or SiF_4 are let through the tube as a standard MCVD process and the elements are embedded in the final preform.

Two discs 32 preferable from silica have been prepared with holes for placing the elements 31 and one or more holes 35 for allowing a flow of process gas 34 through the arrangement. The arrangement may be placed in an MCVD or PCVD deposition tube 33 and the discs are kept in place by heating the tube till it fuses to the discs. The MCVD or PCVD process is carried out in a usual manner as known to a person skilled in the art, thereby causing an incorporation of the arrangement in the deposited glass. The same scheme may be carried out using the VAD or the OVD process by placing the elements in a similar structure around the deposition rod thereby burying the arrangement in the soot during the deposition process (see schematic illustration for the OVD process in Fig. 4). The soot may be sintered at regular interval during the process to avoid the formation of bubbles. The elements may be placed on the surface of the deposition rod or tube in order to ensure an accurate radial position in the final preform. This process may be repeated to embed several layers of elements.

In a fourth aspect, the present invention relates to deposition of doped and/or undoped glass materials around a rod or tube until the rod or tube (these being referred to as elongated elements) are at least partly buried by the deposited material, such that a preform body comprising a plurality of elongate elements results.

Fig. 4 shows an assembly of rod and/or capillary tube elements 41 placed in a couple of discs (preferably of quartz) 42 for ensuring their positions. The discs are placed on a deposition rod or tube 43 and the deposition process can be either VAD or OVD. The element array is

embedded in the final preform. A heating source 44 is indicated.

The above-described scheme or method takes advantage of well-understood standard processes, and offer a solution to adding the holey or doped structure to the final preform.

In a fifth aspect, the present invention relates to forming holes in a porous glass body.

Most preform fabrication processes (VAD, OVD, sol-gel) involve as an intermediate step, the formation of a porous body, which is later sintered to a solid body forming the finished preform. The porous body is more amenable to processing than the solid. The present inventors have found methods to form structures in the porous body that remain in the final solidified preform. The holes - or voids - may be made in a number of ways, such as for example by traditional drilling (rotary or ultra sonic drilling), or for avoiding contamination the holes may be "drilled" by a CO_2 laser (see schematic illustration in Fig. 5).

Fig. 5 illustrates the CO_2 laser "drilling" 51 of a sol-gel body 52 before the sintering step. The holes 53 can be placed arbitrarily. This method provides means for a clean process that will allow a wide range of preform designs, and consequently fibre designs, to be produced. After solidifying the processed gel, the holes may remain as they are, or doped rods and/or tubes may be inserted according to the fibre design.
In a sixth aspect, the present invention relates to solidification of a porous body around electrically resistive elements.

Fig. 6 illustrates an alternative method to drilling to form holes in a porous body. The holes are created by electrically resistive filaments (or rods) placed in the porous body. The array of filaments forming the desired structure is maintained in the similar manner as the elements 11 or 41 in figure 1 or 4. The porous body containing the filaments is locally solidified in vicinity of the filaments when current is flown through so as to reach a temperature in the range of around 1300 to 2000 °C (for instance tungsten, tantalum, rhenium are suitable for this temperature range). Other temperature ranges may apply depending on the preform material. The solidification creates a gap around the filaments. This gap enables removal of the filaments, leaving an array of holes in the porous body. In the final step the porous body is solidified while the holy structure is retained.

Fig. 6 illustrates this method when a sol-gel process is used to form the porous body. A vessel for casting sol-gel body is shown 63. There is a bottom 64 and a top fixture plate 62 in the vessel. High temperature electrical conducting wires 61 are held between the two plates. The solution of silica alkoxide, water and relevant additives is poured into the vessel. The sol is brought to gel. The wires are detached from the top and bottom plates and the gel body 65 is gently removed from the vessel. The body undergoes the usual drying and purification steps as is described in reference to Fig. 1. Due to the reactive gasses involved in the purification step, the wires can be coated prior to the placement in the vessel. One type of coating is silica. This can be added by placing the wires in silica powder and letting a current through the wires so that they heat up in the powder. This will cause

the powder to melt on the surface of the wires. This may take place in an oxygen free atmosphere, e.g. in He or Ar.

After drying and purification of the porous gel body, the wires are heated up by letting through a strong current. This is to take place in an oxygen free atmosphere. The silica will solidify around the wires and hence causing a gap around the wire. If a relative displacement, e.g. circular, between the gel body and the wire is made at a slow speed the holes can be enlarged. The filaments need not be straight. For instance, spiral-shaped filaments can be placed in the gel body. When translated, it will act as a filament having the same diameter as the spiral. After the holes have been formed and the filaments have cooled off, the filaments can be removed from the gel body. The gel body is then solidified to a dense silica glass preform containing an array of holes.

In a seventh aspect, the present invention relates to microstructured optical fibre preform fabrication from deposition in machined bulk glass.

The seventh aspect of the invention is a scheme based on drilling holes in a quartz tube or rod by mechanical drilling (rotary or ultra sonic drilling), where plasma deposition is carried out in the holes. The deposition may be carried out in the holes individually such that each hole may have a different content than its neighbour, or it may be carried out on a number of holes simultaneously (see schematic illustration in Fig. 7).

Fig. 7 shows a quartz cylinder (could also be a tube) 71 with holes 72 that have been drilled mechanically. By

letting in process gas 73 through the holes and placing a plasma coil 74 around the cylinder, plasma CVD can be carried out. The holes 72 can have individual dopants in the deposited glass.

The here-disclosed method is versatile, thus allowing a great degree of freedom for designing fibres. The plasma deposition technique itself is known to be robust and well proven, and very low impurity levels have been reached by this method. In contrast with the modified chemical vapour deposition (MCVD) process where the substrate tube is heated from the outside (and possibly poorly conducted to the inside because of the very low thermal conductivity of silica), in the plasma deposition technique the heat is applied from the inside, where the deposition process occurs. Therefore the applied heat is modest, hence reducing the risk of deforming the preform structure.

According to an embodiment of the eighth aspect of the invention, the present invention relates to the fabrication of a microstructured optical fibre preform from machined bulk glass.

The present invention covers a scheme that is based on drilling holes in a glass tube or rod, e.g. silica or doped silica, by mechanical drilling (for example rotary or ultra sonic drilling). The dopants may for example be Ge, Sn, B, N, P F or a rare earth. The length of element is typically from 20 mm to 500 mm and the diameter is typically in the range of 5 mm to 150 mm. In US patent 2001/0038740A1, fabrication of microstructured optical fibre preforms by drilling holes in bulk silica (quartz) glass is disclosed. The focus is on ways of drilling

holes in silica. The present inventors have realized that it is an advantage to add various glass rods or tubes in one or more of the holes. The holes are typically of 0.5 mm to 10 mm in diameter. The holes remain as holes during draw and the holes in which a doped rod or tube is inserted become doped areas in the final fibre. The dopants of interest are among those mentioned above. The scheme provides further flexibility for realizing new designs of microstructured fibres. Fig. 8 shows a schematic illustration of a prior art preform made by an established preform production method using hexagonal stacking of capillary tubes and doped rods. As opposed to the established stacking technique (see for instance Russell et al. Optical Fiber Communication Conference, Tutorial Session, TuL, 2001) dopants and holes can be placed at any position in the fibre using the here-disclosed method. Furthermore, this process is more amenable to automation (for instance by use of a CNC machine). When a mechanical drilling scheme is used impurities may be introduced. The processed glass may be washed, preferably by using an acid (such as for example a 5% HF, 45% H2SO4, 50% deionised water solution). The drilling may leave a scratched surface that is not wanted due to potential scattering loss in the fibre. Therefore, polishing of the holes before draw may be needed for low loss applications. An alternative to polishing is to insert a sealed capillary tube in a drilled hole, where a hole is wanted in the preform. After drawing to a cane, the capillary tube may have become a hole in the preform providing a surface quality superior to that of a drilled hole.

The here-disclosed method is applicable for a great variety of designs. A potential limitation is related to how dense holes may be placed. The method may be pre-

ferred for designs with a limited number of holes/voids. One of the advantages of this scheme is when the glasses involved in a preform differ in softness. When stacking capillary tubes in the traditional manner, misplacement during heat treatment (for example during drawing) easily occurs in regions of capillary tubes with mixed softness (see doped regions 93 in Fig. 9).

Fig. 9 is a microscope picture of a cane 91 made from the prior art preform schematically illustrated in Fig. 8. It consists of glasses with a difference in softness. Outside the ring with 6 holes 92, 6 softer rods 93 are placed, but it is evident from comparing Fig. 8 and Fig. 9 that they have shifted from their original position in the preform. Furthermore, the doped regions 93 have been deformed by the collapse of the interstitial gaps of the preform.

Fig. 10 shows a design of a drilled preform according to the present invention. Here, 13 holes are drilled in a silica rod 301. The central hole and the six outer holes are filled with the doped rods 3000 and 3003, respectively. The doped rods will keep their positions in the drilled bulk silica 3001.

The fabrication of preforms according to the present invention does not only apply for silica based glasses, but can be applied to other glasses, which e.g. are potential better candidates for fibres with high non-linearities. Tubes of compound glass with smooth surfaces and low geometrical tolerances are not readily available. It is therefore an advantage over the stacking technique that the preforms of the present invention do not require tubes but simply bulk samples, preferably cylindrical in shape.

The present invention also relates to a ninth aspect of fabrication of a preform for a microstructured optical fibre from machined bulk glass. This is illustrated in Fig. 11, where, due to limitation on uniformity and directionality on drilling long holes in glass (e.g. silica), it is suggested to drill in shorter glass elements 4001, discs or rods, which can be stacked later on in a sleeving tube 4005. The size of the glass elements is typically in the range of 25-500mm for the length and 5-150mm for the diameter. The holes 4002 are typically from 0.5-10mm in diameter. Rods or tubes 4006 can be inserted in one or more holes in order to ensure alignment of the elements 4001 so that the holes run continuously through what is to become the preform, see Fig. 11. The alignment rods and tubes 4006 can be left in the holes as elements in the final fibre. Using capillary tubes for lining holes 4002 may reduce the potential problems of rough and scattering surfaces of the drilled holes, and hence alleviate the need for polishing the drilled holes.

The sleeving tube 4005 can be closed in the lower end and a dummy glass rod can be the first element for drop-off at drawing. A dummy rod can be placed as the last element also, ensuring a constant heating of the elements during the pull. The alignment rods or tubes 4006 can be removed before draw. The preform can be drawn to a cane, which can be drawn to a fibre later on. In the transition from one element to another there may be an area of imperfection in the caned preform. When this is the case, the length of preform cane between two such areas may give the maximum length of a flawless preform cane. Alternatively, the preform cane is drawn to fibre and the defect fibre is simply cut out. Ensuring a smooth and even surface at the ends of the elements 4001 (e.g. by

grinding and polishing) may minimize the effects of going from one disc to another during draw.

After a pull or draw of the preform, the top dummy element may have taken the shape of a draw cone, and in case of a long sleeving tube the remains of the dummy element can act as the drop-off element for yet another such preform. The preforms according to embodiments of the ninth aspect are not only limited to silica based glasses for the same arguments that was discussed above in the eighth aspect of the invention.

While the invention has been particularly shown and described with reference to particular embodiments, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention, and it is intended that such changes come within the scope of the following claims.

Fig. 12.a illustrates the stacking technique employed for the first realization of photonic crystal fibres, a process described by Birks et al. in Photonic Band Gap Materials, Kluwer, 1996. The elements 100 had a hexagonal cross-section and a well-defined size. The cladding was formed by elements having a central air hole (capillaries) while the core was formed by an element with no air hole (a rod). The hexagonal elements 100 were bundled by tantalum wires (not shown here), forming a hexagonal preform for fiber pulling.

Fig. 12b illustrates a latter version of hexagonal stacking. It was realized that the capillaries 110 did not need to be hexagonal. The capillary holes 111 could be maintained while the interstitial holes 113 were

collapsed during fibre pulling (see for example US5802236 for fabrication of such fibre - further information on fabrication of microstructured fibres may for example by found in EP1172339 or WO0060388). That alleviated the need for milling the capillaries' preform to a hexagonal tube, thus reducing processing time and surface contamination. The hexagonal stack was placed in a sleeving tube 112 along with supporting elements 114.

The hexagonal stacking technique is only suitable for elements of the same size. But it can be desirable to stack elements of different sizes. Fig. 12c illustrates the case where a larger element 121 is inserted between smaller elements 120 in a sleeving tube 122. Close packing is not achieved. The interstitial holes 123 between elements 120 vary in size.

It is an advantage of the hexagonal structures that they can be produced with good uniformity. However, it is a disadvantage of this scheme that the number of elements per layer is determined by the radial position of the layers: one element is placed in the centre of the preform, six elements are placed in the first layer surrounding the centre element, twelve in the second layer, and 6*n in the n'th layer.

The present inventors have realized a scheme schematically illustrated in fig. 13.a that allows for more flexibility than prior art stacking schemes. This is achieved by the use of the tubes 202 separating each layer, in which the elements 200 are sandwiched. In contrast to the traditional hexagonal stacking, the number of elements in a ring (or layer) can be chosen regardless from the number of elements in the other rings. Correspondingly there is flexibility in the choice of bridge thickness of a

holey structure (the bridge thickness being defined as the smallest distance in a cross-section of the fiber between two adjacent elements). Fig. 13b further shows examples of the flexibility of a preferred embodiment of a method for producing a preform. Here, fillings 1004 of the gap between tubes 1001, 1002 are used to form hybrid elements. These elements may be stretched, drawn or otherwise processed to form hybrid elements or parts for making preforms for optical fibres. As it can be seen a great number of combinations are possible using tubes, rods, other types of elements and/or combinations of these.

The elements to be stacked are substantially circular in shape and will typically be a few hundreds of microns to a few millimetres in diameter. The central element 201 could even be a few tens of millimetres in diameter. The elements would in most cases be pulled on a tower so their length can easily be varied from a few centimetres to a few meters. Typically they would be longer than ten centimetres and shorter than two meters to yield sufficient yet manageable stack preform length for subsequent pulling to fibre. The elements are in most cases made of glass, but other materials such as polymers, metal or combinations of these materials may be used. The glass generally would contain more than 70 mol% of silica but compound glasses (here defined as containing less than 70 mol% silica) can also serve as material for microstructured fibres, as demonstrated by Hewak et al. in Optical Fiber Communication Conference 2001 (OFC'01), TuC4. Compound glass microstructured fibres are particularly interesting for their nonlinear properties. But when low losses and robustness are sought, silica, and in particular synthetic silica, is the material of choice. An element can also be doped

entirely or in part in order to change its refractive index or/and its viscosity. Typically the doped regions may contain a combination of Ge, P, Al, N, Sn, F, B. For laser and amplifier applications the dopants may also be rare-earths such as for example Yb, Er, Nd. An element can also be hollow. It can be a capillary (having a central air hole) or a microstructure. In the preferred embodiment where the elements are silica based (silica content >70mol%) the tubes 202 can either be made of pure silica, preferably synthetic silica, or of doped silica. The dopants may be present throughout the whole tube volume or in one or many annular regions. They can for instance be deposited as layers in a Chemical Vapor Deposition process. Typically the doped regions may contain a combination of Ge, P, Al, N, Sn, F, B, and rare earths.

In contrast to the traditional hexagonal stacking, the sizes of rod and/or capillary tubes 200 can be chosen regardless from the choices of element sizes in the other rings 202. The elements in the displayed design can also be rods 13007 or doped tubes 13008 as indicated in Fig. 13b.

Each ring can be connected to a pressure chamber, allowing to control structural dimensions and parameters such as air/void fraction in each ring.

Figs. 14a and 14b show a modified version of concentric preform construction scheme outlined above.

In fig. 14a the elements 300 are placed in grooves 301 formed in a tube 302 or a rod (for the central layer), which is tightly sleeved by a larger tube 303. The grooves can be formed at any position on the tube, and

many layers can be stacked. Fig. 14.b shows a similar method were the elements 310 are placed in slits 311 formed through the whole thickness of a tube 312. A particularly effective way of forming the grooves and the slits is to focus the light of the CO_2 laser on the surface of the tube to be processed, as described in PCT/DK02/00154, included here by reference. The focusing, the optical power, and the movement of the laser beam give excellent control on the geometry of the grooves 301 or slits 311.

Fig. 15a is a schematic illustration of a preform based on the concentric stacking scheme illustrated in Fig. 13. An alternate pattern of capillaries 401 and rods 402 is used.

Figs. 15b and 15c are schematic illustrations of fibres obtained from pulling the preform illustrated in Fig. 15a. The size of one or more of the holes may generally be controlled during the pull by pressurizing, see for example US4551162 that also describe methods of controlling interstitial holes. A particularly interesting feature of the concentric stacking is that the azimuthal position of the elements can be chosen freely. The fibres of Fig 15.b&c show an alternate pattern of five high index and five low index sectors. This structure is a microstructured fibre that may allow single-mode operation over a wide wavelength range with a large core diameter.

The present inventors have realized that it is particularly convenient to prepare concentric fibres in several steps. First, basic circular structures may be drawn to cane of the desired dimension, typically a few hundreds of microns to a few millimetres. Figs. 16.a and

16.b show a preform for such a cane. It consists of an inner tube 501 surrounded coaxially by an outer tube 502, where the gap 503 between the tubes is filled with elements 504 or 505. Alternatively the elements can be inserted in grooved or slits as illustrated in fig. 14. The same elements as described in relation to fig. 13 can be used. As an example the elements are unsealed capillaries 504 in fig. 16a and sealed capillaries 505 in fig. 16b. Combinations of sealed and unsealed capillaries are, naturally, also within the scope of various preferred embodiments of the present invention. By pressurizing the inner tube 501 from the inside when pulling, the inner diameter to outer diameter ratio of the cane may be changed from the ratio in the cane´s preform. In the example shown in fig. 16a pressurizing the capillaries from the inside when pulling allows control of the thickness of the holey cane. Applying vacuum between the elements when pulling may also serve, for example, to collapse interstitial holes or control their size.

Fig. 17b shows other preferred embodiments of the present invention, to further illustrate the concepts of Fig. 16a and Fig. 16b. Fig. 17b shows schematically hybrid preform elements in the form of ring-shaped elements comprising at an outer element 10001 (typically a tube), a number of filling elements 10004 (such as tubes, rods, and/or other types of elements), and an inner element 10002 (typically a tube or a rod). The fillings elements are preferably made of doped and/or undoped silica, such as silica doped with one or more rare earths. As it can be seen a great number of combinations are possible.

Alternatively, a hybrid preform element (also referred to as a basic element) may be drawn to cane of desired dimensions. By for example pressurizing the inner tube from

the inside when pulling, the diameter of an element may be control. Pressurizing the capillaries or the slits or grooves from the inside when pulling or stretching, the dimensions of a basic element may also be controlled. Applying vacuum between the capillaries when pulling may also serve, for example, to collapse interstitial holes or control their size - as described for Fig. 16a and Fig. 16b. A set of canes drawn from basic elements may be produced in a manner so that they fit into each other to form a preform (see schematic illustration in Fig. 17a). Fig. 17a shows a preform 600 consisting of a central element 601 surrounded by circular rings 602, 603. The thickness in a ring is independent of the choice made for the neighbour rings. Each ring may be connected to a pressure chamber, allowing control of the air fraction (or another gas than air) in each ring in a simple manner.

The present inventors have realized that the scheme using building blocks (such as the canes from hybrid preform elements) as described above, is advantageous for large-scale production, since the preform may be easy to assemble from the caned elements. Another advantage is that the preforms may be round. From the standard hexagonal stacking of capillary tubes the present inventors have observed that problems may arises at the outer corner elements of the hexagonal stack where the stack touches the inside of a sleeving tube. Using circular designs, as covered by the present invention, the problems at corners are eliminated and more stable preforms may be fabricated. Hence, the here-disclosed scheme provides improvements by ensuring a circular structure.

This may even be the case for fibre pulled from non-perfect canes where the structure has been seen to be more

uniform on fibre level (see Fig. 18). Fig. 18a and 18b show an example of circular structure on cane level and on fibre level, respectively. Fig. 18a shows the cane 701 where some imperfections 702 of the holey features 703 are present. On Fig. 18b a fibre 705 drawn from the cane of fig. 18a is shown to have a more uniform structure of the microelements 706. It seems that the fibre structure is locked to a stable condition with strong angular uniformity and a locked radial position. For standard hexagonal stacking it is usually the case that imperfections on cane level may get worse on the fibre level.

Figs. 19a and 19b show two examples of fibres which can be realized from concentric designs. The fibre illustrated in fig. 19a has the basic structure of a dispersion compensating fibre, relying on the optical coupling between the two guiding regions 800 and 802, separated by a lower index holey region 801. The fibre illustrated in figure 19.b has the basic structure of a photonic band gap fibre. In this fibre light can be guided in the holey centre 810. If the bridges between holes 811 are substantially thinner than the wavelength of the guided light their influence on the optical properties of a holey layer 812 can be neglected. The thickness of each layer can conveniently be adjusted during the pull as explained above in relation to fig. 17a and Fig. 17b.

Fig. 20d is an example of fibre obtained from pulling the stack shown in cross-section in Fig. 20c, where two microstructured canes are assembled one into the other, as in the assembly scheme illustrated in Fig. 17a and Fig. 17b. The two canes are obtained from pulling the preforms shown in Figs. 20a and 20b. For example, while pulling to cane, pressurizing the holes of the capillaries 901 and 911 more than the air gaps present in the

preforms allows for the capillaries' holes to be maintain while the gaps collapse fully, resulting in the two holey canes shown in fig. 20c. The two canes fuse together while pulled to fibre. To facilitate this process a low pressure may be apply in the sleeving gap 922. The fibre shown in fig. 20d presents the structure of a double clad fibre. The advantage of using a holey structure is that very high numerical apertures can be obtained, an attractive feature for coupling the pump power into the first cladding 933, as for example Danish Patent Application PA 200200158 included here by reference. Furthermore, the shape of the inner cladding 933 can be chosen by selectively collapsing some of the holes 921 or by replacing some of the capillaries 911 by rods in the outer cane's preform of Fig. 20b. A non-circular inner cladding 933 is desirable to favour pump absorption in the core 930. The presence of holes 931 in the first cladding 933 can serve to modify the propagation of the signal in the core 930, in particular to favour single mode operation.

The stacking scheme illustrated in Fig. 21 consists in concentric layers around the centre element 1001, each with a given number N of elements (N>2). The size of the elements in each layer is chosen so that each element of a given layer is in contact with its two neighbours within the layer. If we call R_1 the radius of the centre element 1001, R_2 the radius of an element 1002 of layer 2, the layer of elements directly surrounding the central element 1001, R_3 the radius of the element 1003 of layer 3, the layer of elements directly surrounding layer 2, and R_k the radius of the element of layer k, the layer of elements directly surrounding layer (k-1), we obtain from geometrical considerations:

$$R_2 = R_1 \frac{\sin\left(\frac{\pi}{N}\right)}{1-\sin\left(\frac{\pi}{N}\right)} \qquad [E1]$$

And for the layer k, k>2:

$$R_k = R_2\, y^{k-2} \quad with\; y = x + \left(x^2-1\right)^{1/2}\; and\; x = \frac{\cos\left(\frac{\pi}{N}\right)+\sin^2\left(\frac{\pi}{N}\right)}{\cos^2\left(\frac{\pi}{N}\right)} \qquad [E2]$$

The outer radius of the layer k, R_k^{out}, is given by:

$$R_k^{out} = R_k \frac{1+\sin\left(\frac{\pi}{N}\right)}{\sin\left(\frac{\pi}{N}\right)} \qquad [E3]$$

For example in Fig. 21 there are 7 concentric layers of N=18 elements. Assuming a central element of radius R_1=10, close packing is obtained with radii $R_{2..8}$= 2,1014; 2,8475; 3,8586; 5,2286; 7,085; 9,601; 13,010, as calculated from equations [E1] and [E2]. The outer radius of the structure 1004 is R_8^{out}=87,93 as calculated from [E3].

In practice the radii of the elements will show some deviation from the target radii calculated. The deviation will typically be +1 to -1% of the target radius but up to +5 to -5% may be tolerated. The elements to be stacked

are as described in relation to Fig. 13a and Fig. 13b. Note that the preform fabrication of Figs. 13a and 13b, where one or several layers of elements are placed between two interfacial tubes 202, may be best used in combination with the stacking technique described here.

Fig. 22a is a schematic illustration of a preform made of 4 concentric layers of capillaries 1100 with central hole 1102 around a central element 1101. The stack is placed in a sleeving tube 1104. Each layer consists of N=16 capillaries 1100. In this figure the inner diameter to outer diameter ratio is the same for all capillaries 1100 but it can of course be varied if required.

Fig. 22b is a schematic illustration of a fibre obtained from pulling the preform illustrated in Fig. 22a. The interstitial gaps 1103 have been collapsed while the holes 1102 have been maintained to obtain the holes 1112 in the fibre.

Fig. 22c is a similar to Fig. 22a but the capillaries 1100 are replaced by the rods 1120. Stacking rods may be preferable to stacking capillaries in order to reduce scattering losses in the fibre because cleaning the outer surface of rods is easier than cleaning both the outer and inner surfaces of capillary tubes.

Fig. 22d is a schematic illustration of a fibre obtained from pulling the preform illustrated in Fig. 22c. Contrary to Fig. 22b, the interstitials gaps 1123 have been maintained to obtain the holes 1133 in the fibre. This is usually done in two steps. First, the preform is pulled to cane with sufficiently low heating to avoid the collapse of the interstitial gaps 1123, but with sufficient heating to fuse each element 1120 to its neigh-

bour. In a second step, the resulting cane, usually inserted in a tube, may be sealed or pressurized in an end opposite to the pulling end in order to control the hole size(s) when pulling to fibre. During the pull the holes 1133 tend to take a circular shape under the effects of surface tension and air (or gas) pressure inside the holes. Alternatively, capillary tubes may be introduced in the interstitial gaps 1123 of the preform illustrated in Fig. 22c. (Fig. 20a shows an example of such an insertion of capillaries) and pressurized to maintain the capillaries' holes during the pull while all the gaps, maintained at a lower pressure, collapse.

In fact many holey patterns can be obtained. For example, starting from the structure shown in Fig. 23a (4 layers of N=16 elements), the fibre structures schematically illustrated in Figs. 23b, 23c, 23d, and 23e can be obtained. To realize these fibre structures we can start with a preform made of capillaries as illustrates in Fig. 22a, collapsing all the interstitial holes 1103 while selectively collapsing some of the capillary holes 1102. This may, for example, be done by sealing some of the capillary tubes (those that are to remain open), while having others open (those that are to collapse). Alternatively capillaries may replace rods 1120 of the preform shown in Fig. 22c at the positions where holes are desired.

Fig. 23d shows a fibre with an elongated core. This geometry is desirable to obtain a large birefringence. In prior art birefringent fibres based on hexagonal stacking and reported by Hansen et al. in IEEE Photonics Technology Letters Vol. 13, No. 6 (June 2001), the core presented a central waist detrimental to efficient light

coupling. It is an advantage that of the present stacking technique will not favour the formation of a waist.

In this section important design aspects such as cut-off and dispersion is considered for two fibre designs, based on the design shown in Fig. 22b.

Figs. 24a and 24b show the actual structures used in the simulations. The core radius is denoted Λ, and is defined as the distance from the centre of the fibre to the centres of the holes in the inner-most ring. The holes are characterized by a relative hole size, defined as the ratio between the hole radius 1301 and the distance between two neighbouring holes in a ring 1302. This relative hole size is constant throughout the fibre. The core area is defined as the area of the circle 1303 with a radius equal to the core radius as defined above. The background material 1304 in the fibre structure shown in Fig. 24a is pure silica, with a refractive index of n=1.444 at 1550nm. In the simulations presented here, the fibre is truncated and surrounded by air outside the fourth ring of holes 1305. In Fig. 24b a doped region 1306 has been added in the centre of the fibre. This doped region, with a circular cross-section, has a parabolic index profile with a peak value of n=1.473. This corresponds to a 2% up-doping relative to the background material. Fig. 24c is a schematic of a fibre with multiple up-doped regions: The up-doped element in the core is maintained from Fig. 24b, while an up-doped ring 1307 is added by stacking the second ring of up-doped capillary tubes.

Fig. 25a shows calculations of the effective mode area, A_{eff}, for the 10 lowest order eigenmodes, using the equa-

tion (see e.g. G.P. Agrawal: Nonlinear Fiber Optics - Third edition, Academic Press, 2001)

$$A_{\text{eff}} = \frac{\left[\int |\mathbf{H}(\mathbf{r})|^2 \, d\mathbf{r} \right]^2}{\int |\mathbf{H}(\mathbf{r})|^4 \, d\mathbf{r}}$$

Here $\mathbf{H}(\mathbf{r})$ is the magnetic field. The first two eigenmodes corresponds to the two degenerated polarizations of the fundamental mode. The next four corresponds to the second order mode, etc. The fibre simulated is the structure shown in Fig. 24a with 16 holes in each ring, 4 rings and a relative hole size of 20%. The core and fibre areas are indicated on the figure, the latter is defined as the area of the region inside the truncation as shown on Fig. 24a.

For short wavelengths the effective area of the fundamental mode 1401 is seen to be comparable to or smaller than the core area, which indicates a strong confinement to the core. In this region ($\lambda/\Lambda<0.6$) the fibre is expected to provide single mode guidance of light with a low sensitivity to bending.

The higher order modes, on the other hand, are seen to have effective areas that are significantly larger than the core for all wavelengths. This indicates that no higher order modes are supported by this structure. Therefore this fiber exhibits endlessly single mode operation, as it is known from photonic crystal fibers with e.g. a triangular cladding geometry. In the long wavelength region the fundamental mode extends further into the cladding region, but remains guided by the core.

Example:

A fiber designed to guide light with a wavelength of λ=1.55μm. The normalized wavelength is chosen to be λ/Λ=0.2, where Λ is the core radius of the fiber. The core radius is then calculated to be Λ=7.75μm. Radius of the holes in the four inner most rings are: 0.302μm, 0.426μm, 0.600μm, and 0.844μm.

Fig. 25b shows calculations for the same basic design as in Fig. 25a, but with larger holes: (Hole size: 0.30). The fiber is seen to support a second order mode at short wavelengths. Cut-off 1403 occurs for a normalized wavelength of approximately λ/Λ=0.1, corresponding to a core radius of Λ=15.5μm for a wavelength of λ=1.55μm. If a core radius of Λ=7.5μm is used, the fibre remains single mode for wavelengths as low as λ=0.775μm. A normalized wavelength of λ/Λ=0.8, which yields an effective area of the fundamental mode equal to the core area, corresponds to a core radius of Λ=1.9μm.

In Fig. 25c an even larger hole size, 60%, is used. The fibre design remains the same as in Figs. 25a and 25B. The fibre is found to be multi mode for normalized wavelengths shorter than λ/Λ<1.1 supporting both a second 1404 and third 1405 order mode. The third order mode is seen to reach cut-off at a normalized wavelength of λ/Λ=0.4, while no sharp cut-off is seen for the second order mode. For long wavelengths, λ/Λ>1.1, however, the mode is so loosely confined to the core that single mode-like operation is achieved.

Figs. 26a and 26b show calculations performed on the structure shown in Fig. 24b with hole sizes of 20% and 30%, respectively. The up-doped region has a parabolic index-profile with a peak value 2% larger than the background material, which is silica in this case. The radius of the doped region is 0.25Λ.

In Fig. 26a calculations of the dispersion in the fundamental mode has been included. The minimum value of the dispersion is seen to occur at a normalized wavelength of λ/Λ=0.2. This is in the single mode region of the fibre. If this normalized wavelength is chosen, and the fibre is operated at a wavelength of λ=1.55μm, the core radius is Λ=7.75μm, and the waveguide dispersion is found to be $D_W = -41\text{ps/km/nm}$. This yields a total dispersion of $D = -24\text{ps/km/nm}$. If the operational wavelength is λ=0.98μm, the core radius is Λ=4.9μm, and the dispersion $D = -105\text{ps/km/nm}$ (Waveguide dispersion: $D_w = -60\text{ps/km/nm}$, material dispersion: $D_M = -45\text{ps/km/nm}$).

In Fig. 26b robust single mode operation is seen for a large range of normalized wavelengths between λ/Λ=0.2 and λ/Λ=1.0. This corresponds to core sizes between Λ=1.55μm and Λ=7.75μm for an operational wavelength of λ=1.55μm.

PREFORM, METHOD OF ITS PRODUCTION, AND USE THEREOF IN PRODUCTION OF MICROSTRUCTURED OPTICAL FIBRES

CLAIMS

1. A method of making a preform for a microstructured optical fibre, said method comprising:

a) providing a tubular vessel having a length;
b) providing a plurality of elongate elements extending at least a portion of said length and being maintained in a predetermined spatial arrangement with respect to the vessel;
c) filling at least a portion of said vessel with a silica-containing sol;
d) permitting or causing said sol to gel to thereby form a wet gel body; and
e) drying said wet gel body, such that a dried or at least partly dried gel body comprising said plurality of elongate elements results.

2. The method according to claim 1, wherein step c) is performed before step b).

3. A method according to claim 1 or 2, wherein the drying step e) includes or further includes sintering of the gel body.

4. The method according to claim 3, wherein the sintering process is performed after the drying process, such that a dried or at least partly dried and sintered gel body comprising said plurality of elongate elements results.

5. The method according to claim 4, wherein said drying step e) further includes purifying of the gel body, such that a dried or at least partly dried, purified and sintered gel body comprising said plurality of elongate elements results.

6. A method according to any of the claims 1-5, wherein the elongate elements are maintained in the predetermined arrangement by holding fixtures.

7. A method according to any of the claims 1-6, wherein the vessel is removed after the gelation process of step d) and before the drying process of step e).

8. A method according to claim 6 or 7, wherein the holding fixtures are removed after the gelation process of step d) and before the drying process of step e).

9. A method according to any of the claims 4-8, wherein the sintering process is performed at a temperature in the range of 1100-1600 °C or in the range of 1300-1500 °C.

10. A method according to any of the claims 4-8, wherein the sintering process is performed at a temperature in the range of 1200-1750 °C.

11. A method according to any of the preceding claims, wherein the elongate elements comprise one or more capillary tubes and/or at least one one or more rods.

12. The method according to claim 11, wherein at least part of the one or more capillary tubes are sealed before the filling of at least a portion of said vessel with the sol.

13. The method according to claim 12, wherein at least parts of the sealed capillary tubes are unsealed after the drying or sintering process.

14. A method according to any of the claims 11-13, wherein the one or more rods comprise one or more doped rods.

15. A method according to any of the preceding claims, wherein the dried or sintered body is sleeved in an overclad tube.

16. A method according to any of the claims 11-15, wherein a compound glass is added to one or more of the capillary tubes after the drying or sintering process.

17. The method according to claim 16, wherein the compound glass contains less than 70% of silica.

18. A method according to any of the claims 11-15, wherein a gas is added to one or more of the capillary tubes.

19. The method according to claim 18, wherein said gas filled capillary tubes are sealed after the adding of gas.

20. A method according to claim 18 or 19, wherein the gas is added to the capillary tubes after the drying or sintering process.

21. A method according to any of the claims 18-20, wherein the added gas is containing chlorine or fluorine or an inert gas.

22. A method according to any of the preceding claims, wherein the gel body has a diameter or largest cross-sectional dimension in the range of 10-150 mm or in the range of 20-100 mm.

23. A method according to any of the preceding claims, wherein the gel body has a length larger than 100 mm or in the range of 150-1200 mm.

24. A method of drawing a microstructured optical fibre, said method comprising using a preform according to any of the claims 1-23.

25. The method according to claim 24, wherein a gas is flowing through a number of open capillary tubes during at least part of the drawing process.

26. The method according to claim 25, wherein the flowing gas is containing chlorine or fluorine or an inert gas.

27. A method of making a preform for a microstructured optical fibre, said method comprising:

a) casting at least one sol-gel preform element having a length and a number of grooves extending at least a portion of said length, said grooves being arranged on an outer surface and/or on an inner surface of the sol-gel element; and

b) for grooves being arranged on the outer surface of the sol-gel element, providing one or more outer cover preform elements for covering the outer grooves at least partly along said length; and/or

c) for grooves being arranged on the inner surface of the sol-gel element, providing one or more inner cover preform elements for covering the inner grooves at least partly along said length, said covering of the outer and/or inner grooves thereby providing a number of elongated holes extending in the direction of the length of the preform elements.

28. The method according to claim 27, wherein said at least one sol-gel element comprises an inner sol-gel preform element having a number of grooves being arranged on the outer surface of the inner sol-gel element.

29. A method according to claim 27 or 28, wherein said at least one sol-gel preform element comprises one or more tubular formed sol-gel elements having a number of grooves being arranged on the outer surface of the element and/or the inner surface of the element.

30. A method according to any of the claims 27-29, wherein said at least one sol-gel preform element comprises a first number of curve-shaped elements with a number of outer and/or inner grooves, said first number of curve-shaped elements being arranged so as to form a first compound tube with outer and/or inner grooves.

31. A method according to claim 29 or 30, wherein at least one of said one or more tubular formed sol-gel elements is used as an outer or inner cover preform element.

32. A method according to claim 30 or 31, wherein said first compound tube formed element is used as an outer or inner cover preform element.

33. A method according to any of the claims 27-32, wherein the casting of a sol-gel preform element comprises:

a) providing a vessel having a length and formed as a mould for said sol-gel preform element, said vessel being provided with a number of projections extending inside in the vessel and along at least a portion of the length of the vessel, said projections thereby serving as a mould for said number of grooves;
b) filling at least a portion of said vessel with a silica-containing sol;
c) permitting or causing said sol to gel to thereby form a wet gel body; and
d) drying said wet gel body, such that a dried or at least partly dried gel body comprising said number of grooves results.

34. The method according to claim 33, wherein said drying step d) includes or further includes sintering of the gel body.

35. The method according to claim 34, wherein the sintering process is performed after the drying process, such that a dried or at least partly dried and sintered gel body comprising said number of grooves results.

36. The method according to claim 35, wherein step d) further includes purifying of the gel body, such that a dried or at least partly dried, purified and sintered gel body comprising said number of grooves results.

37. A method according to any of the claims 27-36, wherein the sol-gel preform element has a diameter or

largest cross-sectional dimension in the range of 10-150 mm or in the range of 20-100 mm.

38. A method according to any of the claims 27-37, wherein the sol-gel preform element has a length larger than 100 mm or in the range of 150-1200 mm.

39. A method of making a preform for a microstructured optical fibre, said method comprising:

a) providing a deposition tube having a length;
b) providing a plurality of elongate elements extending at least a portion of said length and being maintained in a predetermined spatial arrangement with respect to the deposition tube; and
c) performing a Chemical Vapor Deposition, CVD, process to thereby deposit a doped glass material in the tube until the elongated elements are at least partly buried by the deposited material.

40. The method according to claim 39, wherein said deposition process comprises a Modified Chemical Vapor Deposition, MCVD, process or a plasma Chemical Vapor Deposition, plasma CVD, process.

41. A method according to claim 39 or 40, wherein the elongate elements are maintained in the predetermined arrangement by holding fixtures.

42. The method according to claim 41, wherein the holding fixtures comprises two discs, each disc having a first number of holes for placement of the elongate elements and a second number of holes for allowing a flow of process gas.

43. A method according to claim 41 or 42, wherein the holding fixtures are made of quartz or silica.

44. A method according to any of the claims 41-42, wherein the holding fixtures are fused to the deposition tube by heating.

45. A method according to any of the claims 41-43, wherein the elongate elements comprise one or more capillary tubes and/or one or more rods.

46. The method according to claim 45, wherein the elongate elements comprise one or more doped or un-doped silica rods.

47. A method according to claim 45 or 46, wherein the elongate elements comprise one or more doped or un-doped capillary silica tubes.

48. A method according to any of the claims 39-47, wherein the preform body has a diameter or largest cross-sectional dimension in the range of 10-150 mm or in the range of 20-100 mm.

49. A method according to any of the claims 39-48, wherein the preform body has a length larger than 100 mm or in the range of 150-1200 mm.

50. A method of making a preform for a microstructured optical fibre, said method comprising:

a) providing a deposition rod having a length;
b) providing a plurality of elongate elements extending at least a portion of said length and being maintained

in a predetermined spatial arrangement with respect to the deposition rod; and

c) performing a Chemical Vapor Deposition, CVD, process to thereby deposit a doped glass material around the deposition rod until the elongated elements are at least partly buried by the deposited material.

51. The method according to claim 50, wherein the deposition process comprises a VAD or an OVD deposition process.

52. A method according to claim 50 or 51, said method further comprising one or more sintering processes during the deposition of the doped glass material.

53. A method according to any of the claims 50-52, said method further comprising the removal of the deposition rod after the deposition of the doped glass material.

54. A method according to any of the claims 50-53, wherein the elongate elements are maintained in the predetermined arrangement by holding fixtures.

55. The method according to claim 54, wherein the holding fixtures comprises two discs, each disc having a first number of holes for placement of the elongate elements and a rod hole for placement of the deposition rod.

56. A method according to claim 54 or 55, wherein the holding fixtures are made of quartz or silica.

57. A method according to any of the claims 54-56, wherein the holding fixtures are fused to the deposition tube by heating.

58. A method according to any of the claims 50-57, wherein the elongate elements comprise one or more capillary tubes and/or one or more rods.

59. The method according to claim 58, wherein the elongate elements comprise one or more doped or un-doped silica rods.

60. A method according to claim 58 or 59, wherein the elongate elements comprise one or more doped or un-doped capillary silica tubes.

61. A method according to any of the claims 50-60, wherein the preform body has a diameter or largest cross-sectional dimension in the range of 10-150 mm or in the range of 20-100 mm.

62. A method according to any of the claims 50-61, wherein the preform body has a length larger than 100 mm or in the range of 150-1200 mm.

63. A method of making a preform for a microstructured fibre, said method comprising:

a) providing a porous or non-solid silica containing body having a length;
b) forming a number of elongate holes or voids extending at least a portion of said length, and after said formation of elongate holes or voids; and
c) permitting or causing said silica containing body to solidify.

64. The method according to claim 63, wherein step c) includes sintering of the body.

65. A method according to claim 63 or 64, wherein said porous or non-solid silica containing body is provided by use of a tubular vessel having a length, filling at least a portion of said vessel with a silica-containing sol, and permitting or causing said sol to gel to thereby form a gel body.

66. A method according to claim 63 or 64, wherein said porous or non-solid silica containing body is provided by use of a deposition rod having a length, performing a chemical vapour deposition process to thereby deposit doped glass on the deposition rod until at least a part of the deposition rod is covered with doped glass.

67. The method according to claim 66, wherein said deposition process comprises a so-called VAD or a so-called OVD deposition process.

68. A method according to any of the claims 65-67, wherein the body is removed from the vessel before the formation of the elongate holes or voids.

69. A method according to any of the claims 63-68, wherein the body is at least partly dried without being sintered before the formation of the elongate holes or voids.

70. A method according to any of the claims 64-69, wherein the body is purified the sintering process.

71. A method according to any of the claims 63-70, wherein the elongate holes or voids are formed by a drilling process.

72. The method according to claim 71, wherein the drilling process comprises a rotary or an ultra sonic drilling process.

73. A method according to claim 71 or 72, wherein the formed holes or voids are washed and etched.

74. A method according to any of the claims 63-70, wherein the elongate holes or voids are formed by use of laser.

75. A method according to claim 74, wherein a CO2 laser is used for said formation of holes or voids.

76. A method according to any of the claims 63-75, wherein one or more rods are inserted in the formed holes or voids after the solidification.

77. A method according to any of the claims 63-76, wherein one or more tubes are inserted in the formed holes or voids after the solidification.

78. A method according to claim 76 or 77, wherein one or more of said rods and/or tubes are made of a doped material.

79. A method according to any of the claims 63-78, wherein the solidified body has a diameter or largest cross-sectional dimension in the range of 10-150mm or in the range of 20-100mm.

80. A method according to any of the claims 63-79, wherein the solidified body has a length larger than 100mm or in the range of 150-1200mm.

81. A method according to any of the claims 63-80, wherein the elongate holes or voids formed in step d) have a diameter or largest cross sectional dimension larger than 0.8 mm.

82. A method according to any of the claims 63-81, wherein the elongate holes or voids formed in step d) have a length larger than 50 mm.

83. A method of making a preform for a microstructured optical fibre, said method comprising:

a) providing a plurality of electrically resistive elements extending in a longitudinal direction and being maintained in a predetermined spatial arrangement with respect to said longitudinal direction;
b) forming a porous or non-solid silica containing body surrounding said electrically resistive elements; and
c) performing an at least local solidification of the porous body around the electrically resistive elements by providing an electrical current through at least part of said elements to thereby create a gap around each of said elements being provided with an electrical current.

84. The method according to claim 83, wherein the electrically resistive elements are arranged substantially parallel along said longitudinally direction.

85. A method according to claim 83 or 84, said method further comprising removal of the electrically resistive elements after said local solidification, whereby the created gaps leaves a number of elongate holes or voids extending in said longitudinally direction.

86. The method according to claim 85, said method further comprising permitting or causing said silica containing body to solidify after the removal of the electrically resistive elements.

87. A method according to claim 86, said method further including sintering of the body.

88. A method according to any of the claims 83-87, wherein said porous or non-solid silica containing body is provided by use of a tubular vessel having a length and surrounding the electrically resistive elements, filling at least a portion of said vessel with a silica-containing sol, and permitting or causing said sol to gel to thereby form a gel body at least partly surrounding said electrically resistive elements.

89. A method according to any of the claims 83-87, wherein said porous or non-solid silica containing body is provided by use of a deposition rod having a length and being surrounded by the electrically resistive elements, performing a chemical vapour deposition process to thereby deposit doped glass around the deposition rod until at least a part of the deposition rod is covered with doped glass and until the electrically resistive elements are at least partly buried by the deposited material.

90. The method according to claim 89, wherein said deposition process comprises a so-called VAD or a so-called OVD deposition process.

91. A method according to any of the claims 87-90, wherein the body is purified before the sintering process.

92. A method according to any of the claims 85-91, wherein one or more rods are inserted in the formed holes or voids.

93. A method according to any of the claims 85-91, wherein one or more tubes are inserted in the formed holes or voids.

94. A method according to claim 92 or 93, wherein one or more of said rods and/or tubes are made of a doped material.

95. A method according to any of the claims 83-94, wherein the silica containing body has a diameter or largest cross-sectional dimension in the range of 10-150 mm or in the range of 20-100 mm.

96. A method according to any of the claims 83-95, wherein the silica containing body has a length larger than 100mm or in the range of 150-1200 mm.

97. A method according to any of the claims 83-96, wherein the formed gaps have a diameter or largest cross sectional dimension larger than 0.2 mm or larger than 0.8 mm.

98. A method according to any of the claims 83-97, wherein the formed gaps are extending in all the length of the silica containing body.

99. A method of making a preform for a microstructured optical fibre, said method comprising:

a) providing a silica tube or rod having a length;

b) forming a number of elongate holes or voids extending at least a portion of said length; and

c) performing a plasma deposition of a doped glass material in one or more of the formed holes or voids.

100. The method according to claim 99, wherein the deposition process is plasma Chemical Vapor Deposition, PCVD, process.

101. A method according to claim 99 or 100, wherein a plasma coil is arranged around the silica tube or rod for use during the plasma deposition process.

102. A method according to any of the claims 99-101, wherein the elongate holes or voids are formed by a drilling process.

103. The method according to claim 102, wherein the drilling process comprises a rotary or an ultra sonic drilling process.

104. A method according to claim 102 or 103, wherein the formed holes or voids are washed and etched.

105. A method according to any of the claims 99-104, wherein the elongate holes or voids are formed by use of laser.

106. A method according to any of the claims 99-106, wherein the doped glass material comprises a dopant selected from the group of dopants comprising: Ge, P, Sn, N, B and F.

107. A method according to any of the claims 99-106, wherein the silica tube or rod has a diameter or largest

cross-sectional dimension in the range of 10-150mm or in the range of 20-100mm.

108. A method according to any of the claims 99-107, wherein the silica tube or rod has a length larger than 100 mm or in the range of 150-1200 mm.

109. A method according to any of the claims 99-108, wherein the elongate holes or voids formed in step b) have a diameter or largest cross sectional dimension larger than 0.2 mm or larger than 0.8 mm.

110. A method according to any of the claims 99-109, wherein the elongate holes or voids formed in step b) have a length larger than 50 mm or larger than 100 mm.

111. A method according to any of the claims 99-110, wherein the elongate holes or voids formed in step b) are extending in all the length of the silica tube or rod.

112. A method of making a preform for a microstructured optical fibre, said method comprising:

a) providing a glass containing body having a length,
b) forming a number of elongate holes or voids extending at least a portion of said length, and
c) inserting one or more rods and/or capillary tubes in the formed holes or voids.

113. The method according to claim 112, wherein the elongate holes or voids are formed by a drilling process.

114. The method according to claim 113, wherein the drilling process comprises a rotary or an ultra sonic drilling process.

115. A method according to claim 112 or 113, wherein the formed holes or voids are washed and etched.

116. The method according to claim 112, wherein the elongate holes or voids are formed by use of laser.

117. A method according to any of the claims 112-116, wherein a CO2 laser is used for said formation of holes or voids.

118. A method according to any of the claims 112-117, wherein one or more of said rods or capillary tubes are made of a doped material.

119. The method according to claim 118, wherein the doped material is a doped silica material comprising a dopant selected from the group of dopants comprising: Ge, P, Sn, N, B and F and rare-earths.

120. A method according to any of the claims 112-119, wherein the glass containing body has a diameter or largest cross-sectional dimension in the range of 5-150 mm or in the range of 20-100 mm.

121. A method according to any of the claims 112-120, wherein the glass containing body has a length larger than 20 mm, in the range of 20-500 mm, or in the range of 150-1200 mm.

122. A method according to any of the claims 112-121, wherein the glass containing body is cylindrically shaped.

123. A method according to any of the claims 112-122, wherein the elongate holes or voids formed in step b) have a diameter or largest cross sectional dimension in the range of 0.5-10 mm or larger than 0.5 mm or 0.8 mm.

124. A method according to any of the claims 112-123, wherein the elongate holes or voids formed in step b) have a length larger than 20 mm, larger than 50 mm, larger than 100 mm, or in the range of 20-500 mm.

125. A method according to any of the claims 112-124, wherein the elongate holes or voids formed in step b) are extending in all the length of the glass containing body.

126. A method according to any of the claims 112-125, wherein the glass containing body is a synthetic silica body.

127. The method according to claim 126, wherein the glass containing body is a doped silica body comprising a dopant selected from the group of dopants comprising: Ge, P, Sn, N, B and F and rare-earths.

128. A preform for a microstructured optical fibre, said preform comprising:

(a) a number of cylindrically shaped bodies having substantially equal radial dimensions, each said body having a number of spaced apart through-holes extending in a longitudinal direction along the axis of the body, the radial position of at least part of

said through-holes being substantial equal for each of the bodies, said bodies being stacked so as to align at least part of the through-holes of the bodies in the axial direction, and

(b) an outer tube contactingly surrounding at least part of the stacked bodies.

129. The preform according to claim 128, wherein the bodies are stacked so that one or more elongate holes extending through several of the bodies are obtained via the aligned through-holes.

130. The preform according to claim 129, wherein at least two or three of said elongate holes are obtained.

131. A preform according to claim 129 or 130, wherein the one or more elongate holes extends through at least two or three bodies.

132. A preform according to any of the claims 128-131, wherein the number of stacked bodies is at least two or at least three.

133. A preform according to any of the claims 130-132, wherein the number of elongate holes extending through several of the bodies is in the range of 3-300.

134. A preform according to any of the claims 128-133, wherein each or at least part of the cylindrically shaped bodies has a substantially planar front surface and/or back surface.

135. A preform according to any of the claims 128-134, wherein each or at least part of the substantially planar

front surface(s) and/or back surface(s) has been grinded and/or polished.

136. A preform according to any of the claims 128-135, wherein the length of each of the cylindrically shaped bodies is larger than the diameter of the body.

137. A preform according to any of the claims 128-136, said preform further comprising one or more rods and/or capillary tubes being inserted in aligned through-holes of at least two successively arranged bodies.

138. The preform according to claim 137, wherein one or more of said rods or capillary tubes are made of a doped material.

139. the preform according to claim 138, wherein the doped material is a doped glass or silica material comprising a dopant selected from the group of dopants comprising: Ge, P, Sn, N, B and F and rare-earths.

140. A preform according to any of the claims 128-139, wherein the preform further comprises a cylindrically shaped dummy body arranged at the top of the stacked bodies with through-holes and having substantially equal radial dimensions as said stacked bodies with through-holes, said top dummy body being contactingly surrounded by the outer tube.

141. A preform according to any of the claims 128-140, wherein the preform further comprises a cylindrically shaped dummy body arranged at the bottom of the stacked bodies with through-holes and having substantially equal radial dimensions as said stacked bodies with through-

holes, said bottom dummy body being contactingly surrounded by the outer tube.

142. A preform according to claim 140 or 141, wherein the dummy body has no through-holes or wherein the number of through-holes in the dummy body is smaller than the number of through-holes in any of the stacked bodies with through-holes.

143. A preform according to any of the claims 128-142, wherein the stacked bodies have been aligned by use of one or more alignment rods and/or tubes inserted in one or more of the through-holes of the bodies to be aligned.

144. A preform according to any of the claims 128-143, wherein the stacked bodies are made of a glass material.

145. A preform according to any of the claims 142-144, wherein the dummy body is made of a glass material.

146. A preform according to claim 144 or 145, wherein the glass material is a synthetic silica material.

147. A preform according to claim 144 or 145, wherein the glass material is a doped silica material.

148. The preform according to claim 147, wherein the doped silica material comprises a dopant selected from the group of dopants comprising: Ge, P, Sn, N, B and F and rare-earths.

149. A preform according to any of the claims 128-148, wherein the cylindrically shaped bodies have a largest cross-sectional area in the range of 5-150mm or in the range of 20-100mm.

150. A preform according to any of the claims 128-149, wherein the cylindrically shaped bodies have a length larger than or equal to 20 mm, larger than or equal to 50 mm, or larger than or equal to 100 mm.

151. A preform according to any of the claims 128-150, wherein the through-holes of the bodies have a largest cross-sectional dimension in larger than 0.5 mm or larger than 0.8 mm.

152. A preform according to any of the claims 128-150, wherein the through-holes of the bodies have a largest cross-sectional dimension in the range of 0.5-10 mm.

153. A preform or part thereof for a microstructured optical fibre, said preform or part comprising:

a) an inner tube or inner rod having a length;
b) a first plurality of cladding tubes and/or rods arranged around said inner tube or rod and extending at least a portion of said length; and
c) a first outer tube surrounding said first plurality of cladding tubes and/or rods.

154. A preform or part thereof for a microstructured optical fibre, said preform or part comprising:

a) an inner tube or inner rod having a length;
b) a first grooved tube having elongated slits and/or grooves extending at least a portion of said length, said first grooved tube surrounding said inner tube or rod; and
c) a first outer tube surrounding said first grooved tube.

155. A preform or part according to claim 153 or 154, wherein a number of pluralities of cladding tubes and/or rods extending at least a portion of said length are arranged in corresponding outer tubes concentrically about the inner tube or inner rod.

156. The preform or part according to claim 155, wherein one or more of the corresponding outer tubes comprises a number of slits and/or grooves extending at least a portion of said length.

157. A preform or part according to any of the claims 153-155, wherein a number of grooved tubes having elongated slits and/or grooves extending at least a portion of said length are arranged concentrically about the inner tube or inner rod.

158. The preform or part according to claim 157, wherein each of said number of grooved tubes is surrounded by a corresponding solid outer tube.

159. A preform or part according to any of the claims 154-158, wherein the number of pluralities of cladding tubes and/or rods is at least two, with the second plurality being surrounded by a second outer tube.

160. The preform or part according to claim 158, wherein said second plurality of cladding tubes and/or rods is arranged around the first outer tube.

161. A preform or part according to any of the claims 154-160, wherein the number of pluralities of cladding tubes and/or rods is at least three, with the third plurality being surrounded by a third outer tube.

162. The preform or part according to claim 161, wherein said third plurality of cladding tubes and/or rods is arranged around the second outer tube.

163. A preform or part according to any of the claims 154-162, wherein the number of pluralities of cladding tubes and/or rods is at least four, with the fourth plurality being surrounded by a fourth outer tube.

164. The preform or part according to claim 163, wherein said fourth plurality of cladding tubes and/or rods is arranged around the third outer tube.

165. A preform or part according to any of the claims 154-164, wherein said number of pluralities of cladding tubes and/or rods is at least five, six or seven.

166. A preform or part according to any of the claims 153-165, wherein one or more plurality of cladding rods comprise one or more doped or un-doped silica rods.

167. A preform or part according to any of the claims 153-166, wherein one or more plurality of cladding tubes comprise one or more doped or un-doped silica tubes.

168. A preform or part according to claim 153 or to claim 153 and any of the claims 154-167, wherein the first plurality of cladding tubes and/or rods is arranged in a single layer only around said inner tube or rod.

169. A preform or part according to claim 153 or to claim 153 and any of the claims 154-167, wherein the first plurality of cladding tubes and/or rods is arranged in two layers around said inner tube or rod.

170. A preform or part according to claim 153 or to claim 153 and any of the claims 154-167, wherein the first plurality of cladding tubes and/or rods is arranged in three, four, five or six layers around said inner tube or rod.

171. A preform or part according to any of the claims 159-170, wherein the second plurality of cladding tubes and/or rods is arranged in a single layer only being surrounded by said second outer tube.

172. A preform or part according to any of the claims 159-170, wherein the second plurality of cladding tubes and/or rods is arranged in two layers only being surrounded by said second outer tube.

173. A preform or part according to any of the claims 159-170, wherein the second plurality of cladding tubes and/or rods is arranged in three, four, five or six layers only being surrounded by said second outer tube.

174. A preform or part according to any of the claims 153-173, wherein one or more plurality of cladding tubes and/or rods is arranged in a single layer only being surrounded by the corresponding outer tube.

175. A preform or part according to any of the claims 153-173, wherein one or more plurality of cladding tubes and/or rods is arranged in two layers only being surrounded by the corresponding outer tube.

176. A microstructured fibre made from a preform or parts thereof according to any of the proceeding claims.

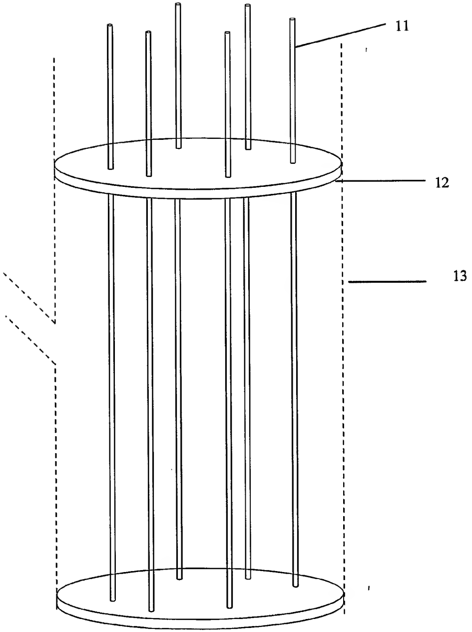


Fig. 1a

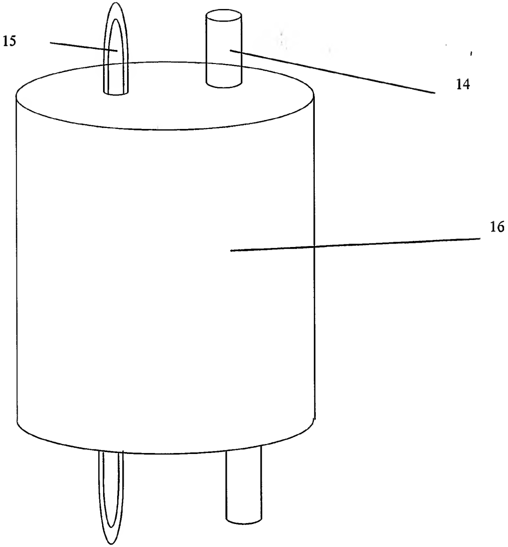


Fig. 1b

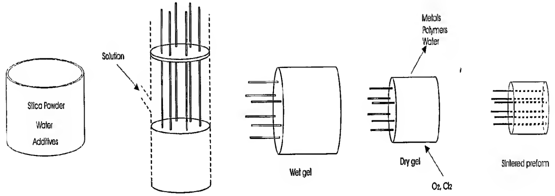


Fig 1c

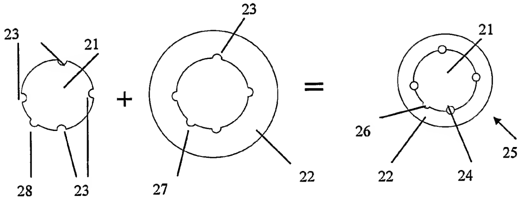


Fig. 2a

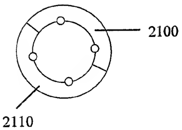


Fig. 2b

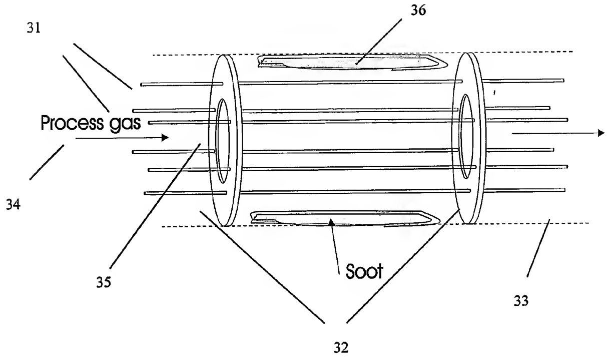


Fig. 3

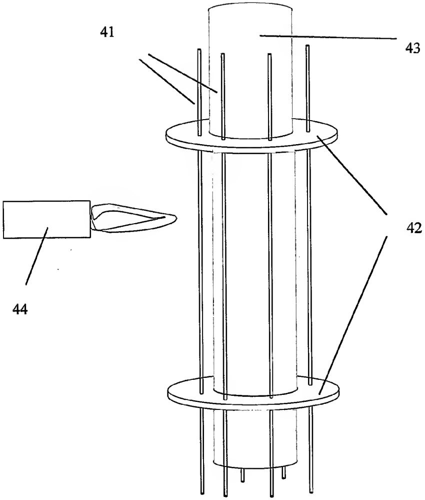


Fig. 4

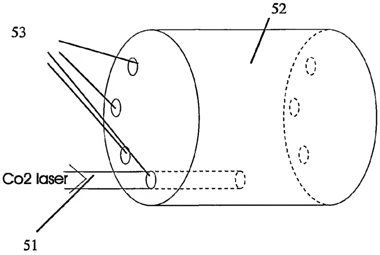


Fig. 5

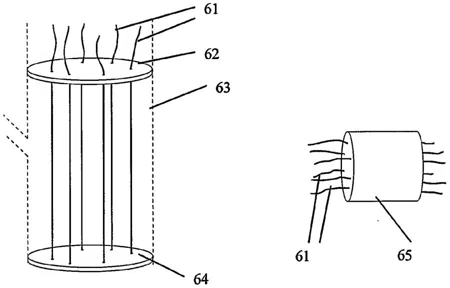


Fig. 6

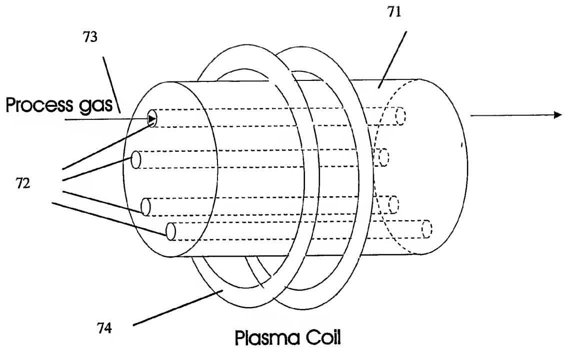


Fig. 7

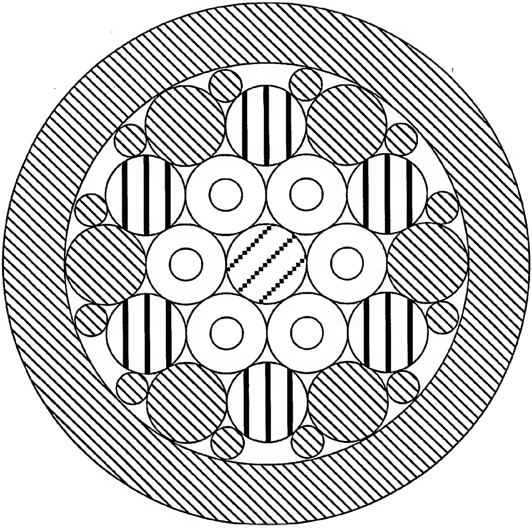


Fig. 8

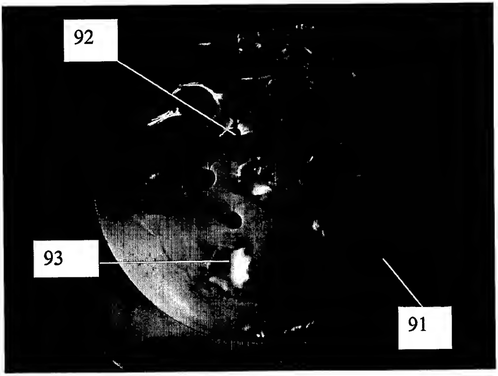


Fig. 9

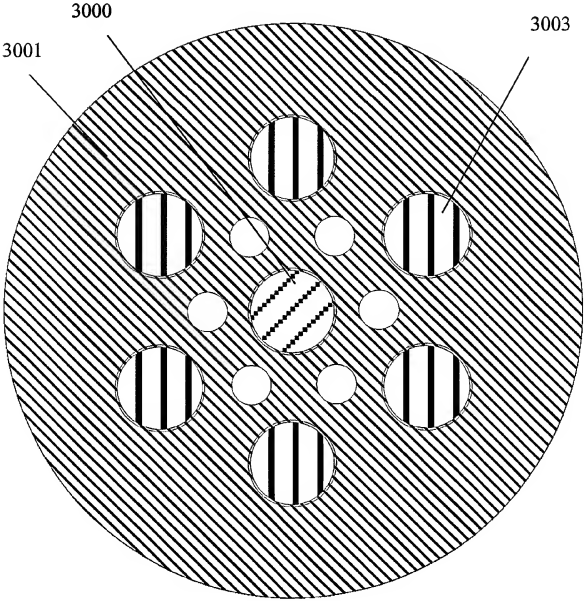


Fig. 10

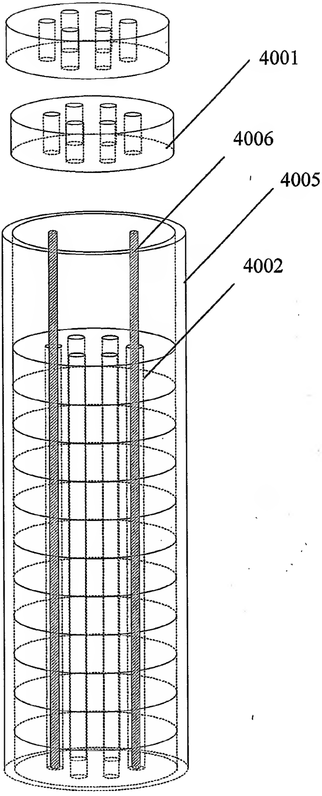


Fig. 11

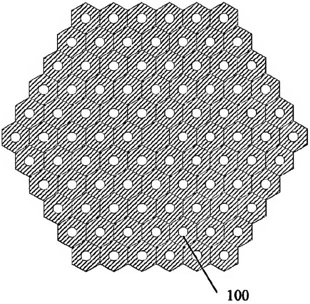


Fig. 12a

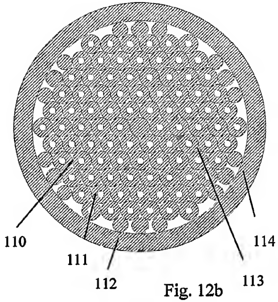


Fig. 12b

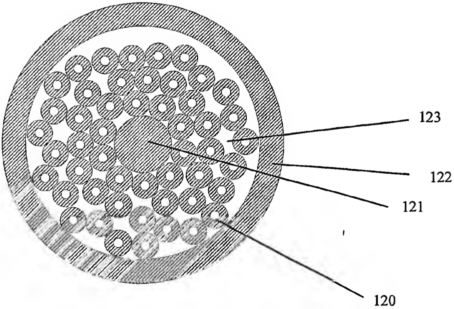


Fig. 12c

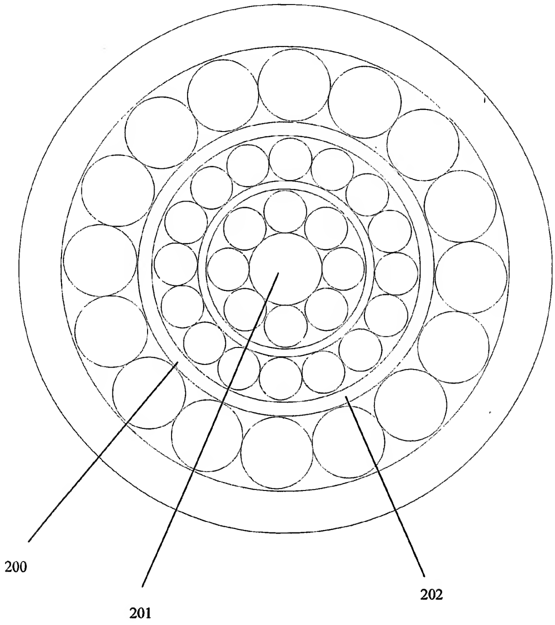


Fig. 13a

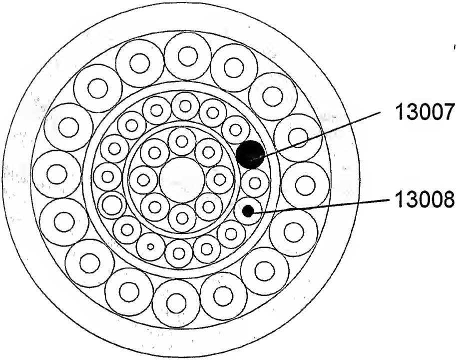


Fig. 13b

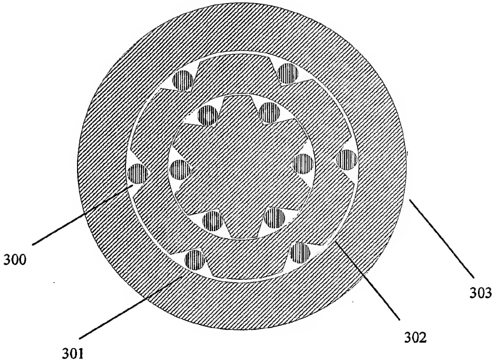


Fig. 14a

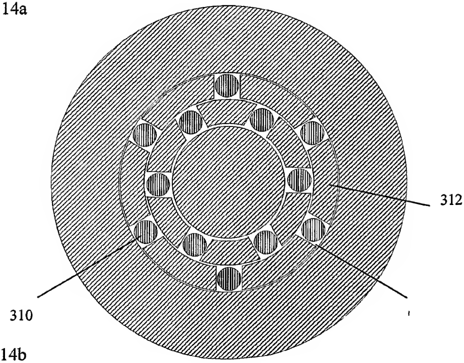


Fig. 14b

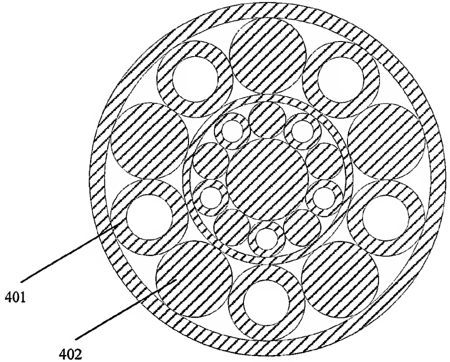
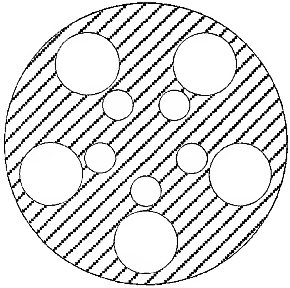


Fig. 15a



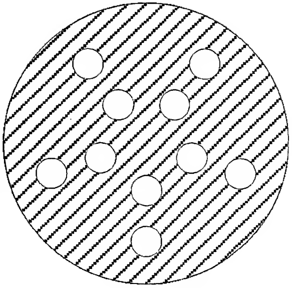


Fig. 15b

Fig. 15c

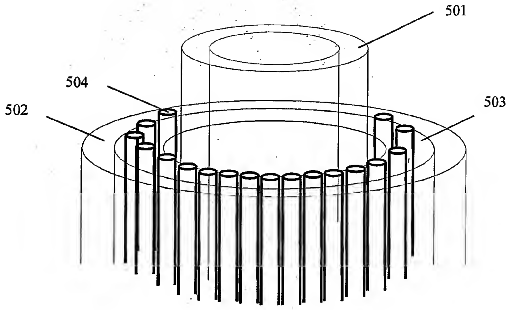


Fig. 16a

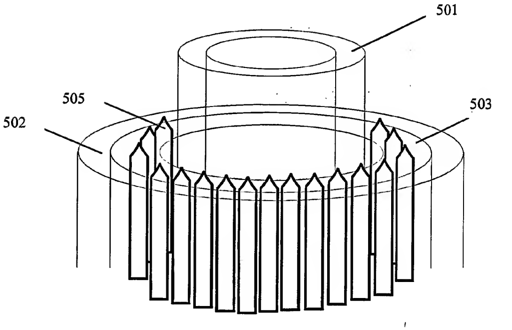


Fig. 16b

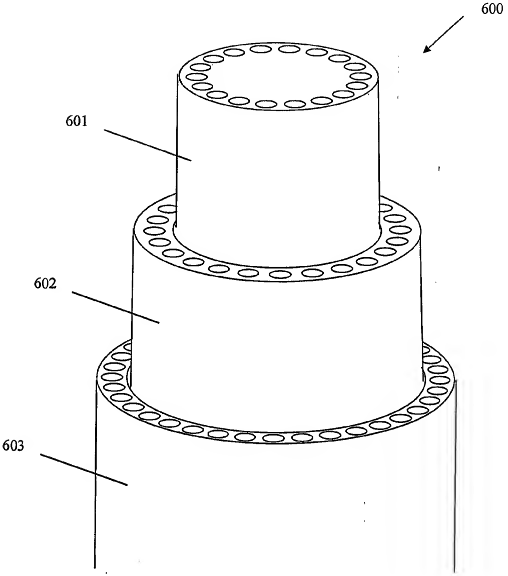
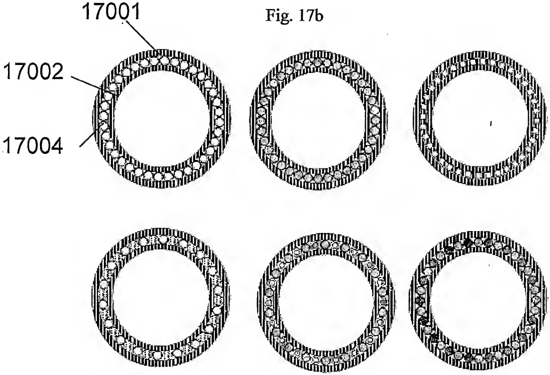


Fig. 17a

Fig. 17b



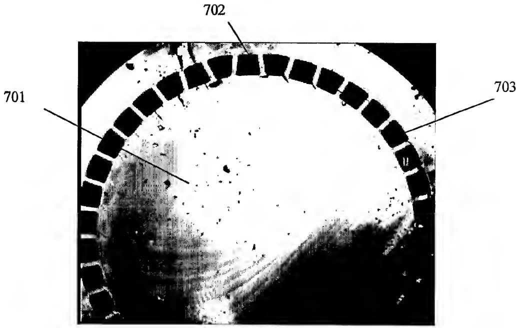


Fig. 18a

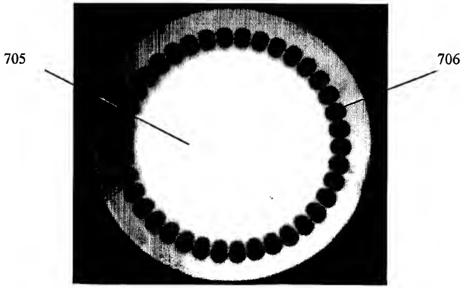


Fig. 18b

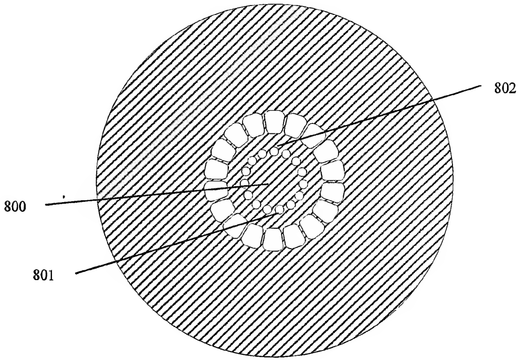


Fig. 19a

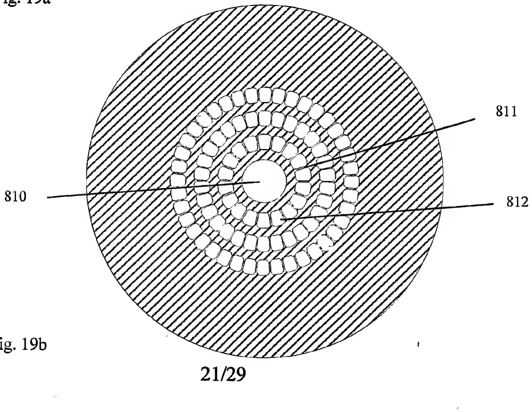


Fig. 19b

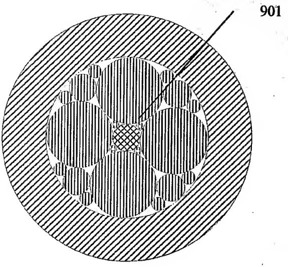


Fig. 20a

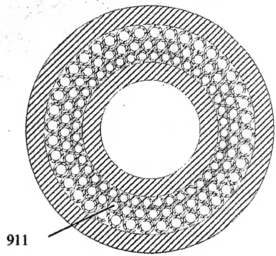


Fig. 20b

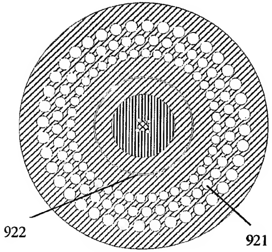


Fig. 20c

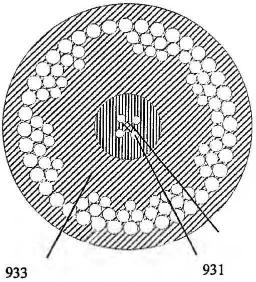


Fig. 20d

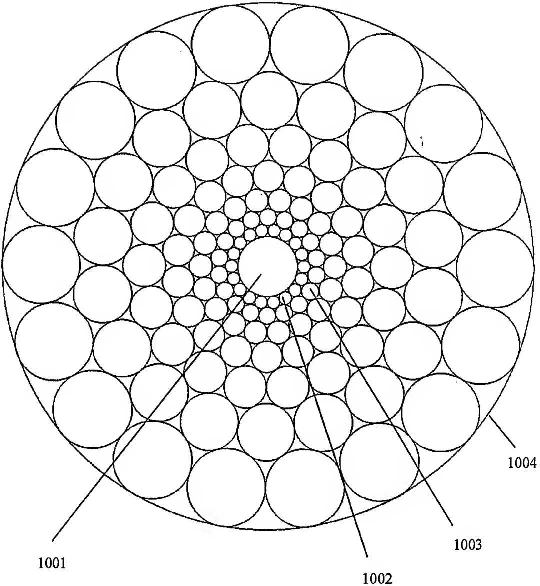


Fig. 21

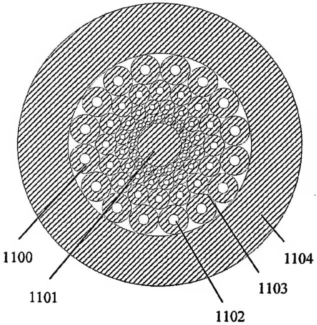


Fig. 22a

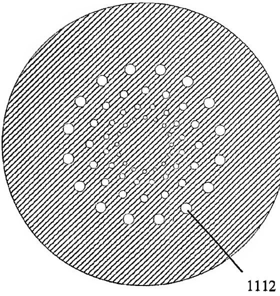


Fig. 22b

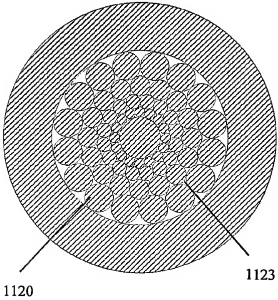


Fig. 22c

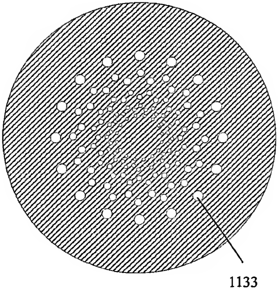


Fig. 22d

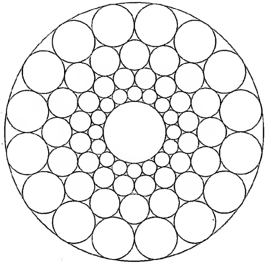


Fig. 23a

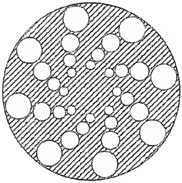


Fig. 23b

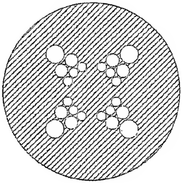


Fig. 23c

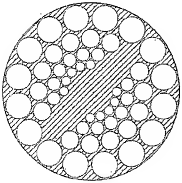


Fig. 23d

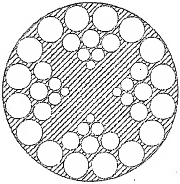


Fig. 23e

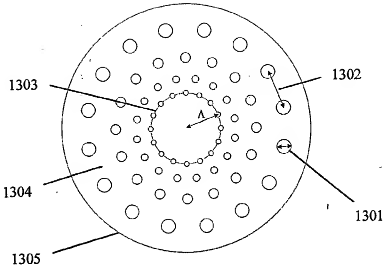


Fig. 24a

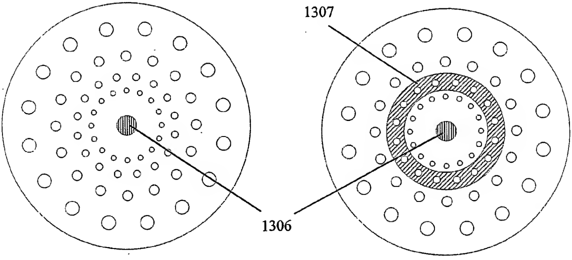


Fig. 24b

Fig. 24c

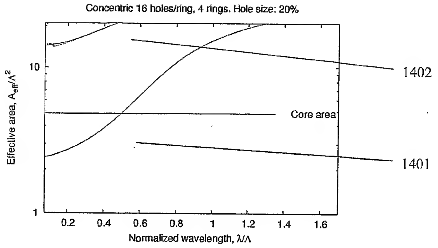


Fig. 25a

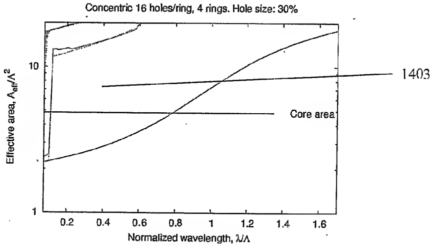


Fig. 25b

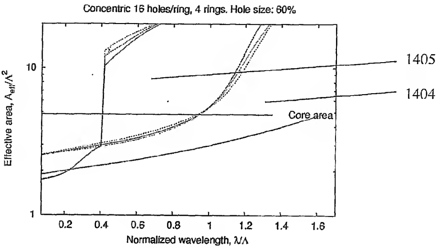

Concentric 16 holes/ring, 4 rings. Hole size: 60%
Effective area, A_{eff}/Λ^2
10
1
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Normalized wavelength, λ/Λ
Core area
1405
1404

Fig. 25c

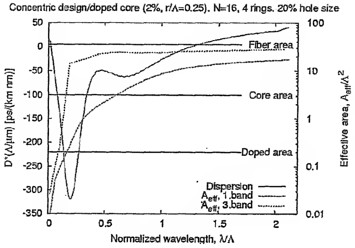


Fig. 26a

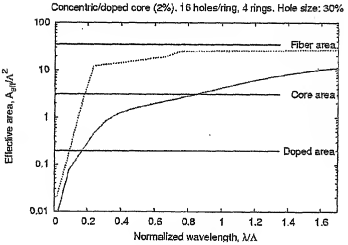


Fig. 26b